NANCEE; AN APPROACH TO BARRIER SONOBUOY PATTERN OPTIMIZATION

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THESIS

NANCEE
AN APPROACH TO BARRIER
SONOBUOY PATTERN OPTIMIZATION

by

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June 1974

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NANCEE is a computer simulation program which uses convolution (or meeting) probabilities to determine which barrier type of sonobuoy pattern has the highest probability of detection for a transiting nuclear submarine.

The program assumes that the optimum barrier is a straight-line one, two, or three row sonobuoy pattern containing not more than 48 sonobuoys. The barrier is centered on the submarine's expected line of transit, oriented perpendicular to the submarine's course, and placed far enough ahead of the

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submarine's position that all pattern sonobuoys are in the water and being monitored before the submarine enters the detection range of the sonobuoy pattern. If more than one barrier is found to have the highest probability of detection, the one with the least number of sonobuoys is selected as optimum.

NANCEE executes rapidly, and is easy to use and understand.

NANCEE
an Approach to Barrier
Sonobuoy Pattern Optimization

by

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NANCEE is a computer simulation program which uses convolution (or meeting) probabilities to determine which barrier type of sonobuoy pattern has the highest probability of detection for a transiting nuclear submarine.

The program assumes that the optimum barrier is a straight-line one, two, or three row sonobuoy pattern containing not more than 48 sonobuoys. The barrier is centered on the submarine's expected line of transit, oriented perpendicular to the submarine's course, and placed far enough ahead of the submarine's position that all pattern sonobuoys are in the water and being monitored before the submarine enters the detection range of the sonobuoy pattern. If more than one barrier is found to have the highest probability of detection, the one with the least number of sonobuoys is selected as optimum.

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To Wally, Nancee, and Diane

My three favorite friends

I. INTRODUCTION

A. THE PROBLEM

Much of the guesswork was removed from aircraft sonobuoy pattern planning with the advent of readily available acoustic propagation-loss curves (see Figure 1). From them, the range at which a sonobuoy will detect a submarine can be estimated by predicting the path of the sound waves in water. Hence a logical estimate of the best sonobuoy pattern spacing is possible. However, two pattern planning questions remain unanswered. They are:

1. What should the shape of the pattern be? (i.e. circular, rectangular, diamond shaped, etc.)

2. How many sonobuoys should the pattern contain?

Some knowledge regarding characteristics of the target is desirable before the optimum sonobuoy pattern shape and number of sonobuoys can be determined. In general terms, the target may have either nuclear or diesel propulsion, and its current mode of operation may be:

1. Transiting (i.e. proceeding from home-port to an on-station position)

2. Holding (i.e. a fleet ballistic missile submarine operating on station)

or,

3. Tracking (i.e. intercepting and/or shadowing a high-value commercial or naval ship)

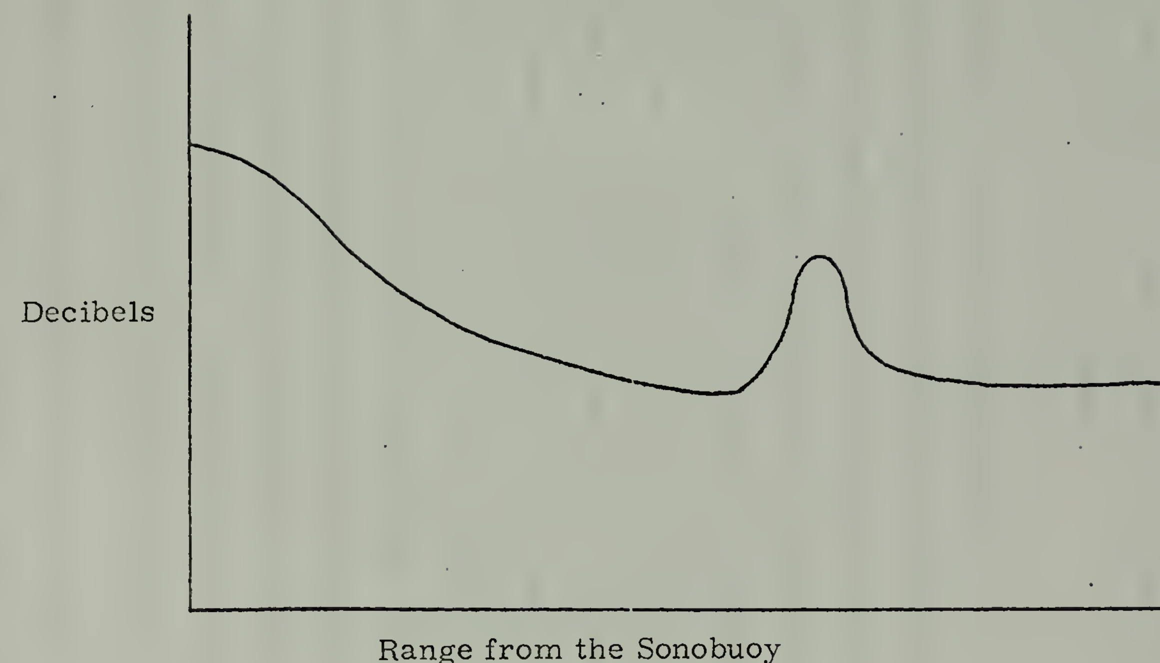

Figure 1

Propagation-Loss Curve Example

An algorithm which would single out the optimum pattern solution for each combination of the above target types and missions is preferred.

The object is to maximize the submarine probability-of-detection (POD) with minimum cost in material. Failure means that the target has been allowed to perform its mission undetected, and the expended pattern sonobuoys, aircraft flight time, flight crew time, and hours of ground preparation were wasted.

B. TENDENCY TO OVERCOMPENSATE

Because of the high cost of failure, there is a tendency to over-compensate and use an excessive number of sonobuoys in the pattern. This tendency would be appropriate if an aircraft could concurrently receive and process information from an unlimited number of sonobuoys, and if there were no limit to the radio-frequency range at which an aircraft could monitor pattern sonobuoys. However, only sixteen sonobuoy channels can be simultaneously monitored by an aircraft, and the sonobuoy monitor range is limited by atmospheric conditions and the curvature of the earth (see Appendix A). Because of the limited radio-frequency range and the aircraft's limited monitoring capacity, there is a maximum number of sonobuoys beyond which no increase of a pattern's POD is possible. No matter how tempting it may seem, exceeding this limit wastes expensive sonobuoys.

C. COMPUTER SIMULATION AS A SOLUTION

In order to determine the optimum pattern it will be necessary to make comparisons between a large number of potential solutions. Because of this, it is natural to turn to computer simulation as a means of solving the problem.

As a matter of fact, considerable effort has already been put forth to develop a computer program which optimizes sonobuoy patterns. Tactical Airborne Sonar Decision Aid (TASDA) [Ref. 2 and 3] is one such program. A good deal of realism has been incorperated into TASDA, and a variety of problem types are considered by it (including the holding and transiting of both nuclear and diesel submarines). Unfortunately, in the development of realism, the program became overly large both in terms of core requirements and program execution time. Repetitive POD computations and comparisons aggravates the execution time problem. Hence, for at least some problems it is necessary to reduce the execution time. A tempting technique is to reduce the number of submarine simulation runs through the sonobuoy pattern for each probability calculation. Unfortunately, this approach leads to a trade-off between a reasonable execution time and accurate probability estimates.

Another problem is that TASDA can consider not more than 20 sonobuoy pattern geometries, and each geometry is limited to 16 or fewer sonobuoys. This is only a small fraction of the patterns which current anti-submarine aircraft are capable of deploying. The addition of more pattern geometries to TASDA, or a program adaption to handle more than 16 sonobuoys per geometry would even further aggravate the execution time problem.

Based on the above considerations, an alternative approach to the sonobuoy pattern optimization problem was investigated.

II. ASSUMPTIONS

Assumptions made in order to limit the problem to realistically solvable terms are:

A. TARGET TYPE

The program should be oriented toward a continuously detectable noise source (i.e. a nuclear submarine) and transiting between two widely separated positions. Although narrowing the problem essentially to transiting nuclear submarines appears to be a severe limitation, bear in mind that long range capabilities make them a primary threat, and in order to reach most positions of operational interest, long transits are necessary.

B. SONOBUOY PATTERN SHAPE AND POSITION

The optimum tactic to be used against transiting nuclear submarines is a straight-line one, two, or three row sonobuoy pattern centered on the submarine's expected line of transit, placed ahead of its current position, and oriented perpendicular to the expected course. However, this is not intended to discourage consideration of "V" shaped (chevron) patterns. A chevron pattern is a simple variation of the straight-line case with a bend at pattern center. Certainly, the bending alters the pattern's POD, but if the bending angle is not large, the detection capability of the chevron pattern can be estimated from the POD of the equivalent straight-line pattern.

C. SONOBUOY SPACING

Sonobuoy spacing should be either determined inside the program or input to the program. The problem is restricted to the determination of the minimum number of sonobuoys which produce the maximum POD, with fixed sonobuoy spacing.

D. SONOBUOY LIMIT

The optimum pattern should contain no more than 48 total sonobuoys. The difficulty in monitoring and maintaining patterns of larger size has a disruptive effect which outweighs any increase in POD.

E. PROGRAM REALISM

Realism must sometimes be sacrificed. For instance, random equipment failures, sonobuoy failures, and monitor sequence disruption (due to prosecution of false contacts, improper adherence to monitor cycle instructions, etc.) are considered too costly to program, and therefore are not included in the program.

III. THE METHOD

A. PROGRAM NAME

With the assumptions of Chapter II as a start, a computer simulation program, hereafter referred to as NANCEE, was developed. NANCEE consists of a main program and seven subroutines:

RANGE

GEOM

TOSS

MEET

BUILD

MAKEUP

OUTPUT

Throughout the following discussion, program variables and arrays appear in capital letters, with their definitions contained in Appendix F.

B. APPROACH TO PROBABILITY CALCULATIONS

A sonobuoy pattern is divided into zones (see Figure 2) and probabilities deemed appropriate for each zone are summed to form an estimate of the pattern's overall POD.

First, the probability that a submarine will pass through each zone of a pattern is estimated (probability 1). Then, for each zone, the probability that a submarine passing through will be detected is estimated (probability 2). The product of these two zone probabilities ((probability 1)x(probability 2)) is the probability a submarine will pass through that zone <u>and</u> be detected. The sum of (probability 1)x (probability 2) for all zones is the sonobuoy pattern POD.

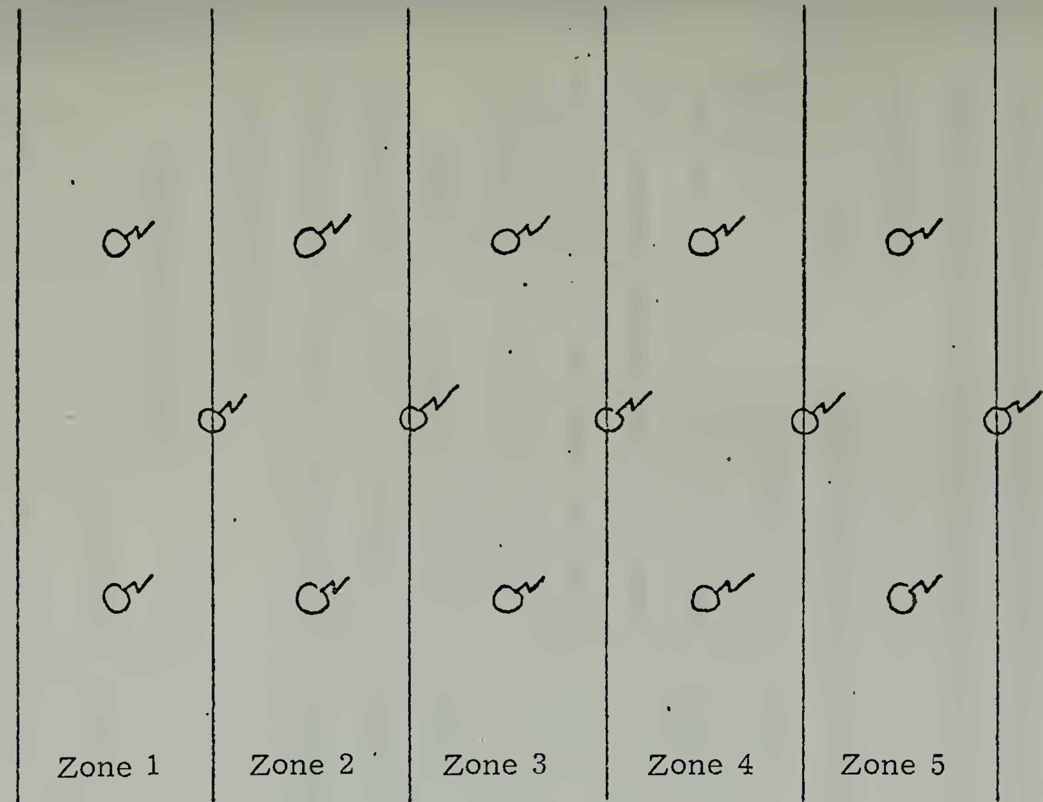

Figure 2

Division of Three-Row Sonobuoy Pattern into Zones

Probability 1 is estimated by using known or estimated submarine characteristics to generate random submarine tracks, and observing where these random tracks penetrate the pattern area.

Convolutional (or meeting) probabilities are used to estimate probability 2. For 10 sizes of predicted detection ranges, the probability that monitor time on at least one zone sonobuoy will overlap the time during which a submarine is within detection range of that sonobuoy is calculated. The average of these 10 calculations is probability 2.

In contrast, TASDA varies the sonobuoy spacing of several sonobuoy pattern geometries (one geometry at a time) from small to large spacings. Submarine simulations through the pattern area are used to generate submarine detections, and these detections are used to estimate POD's for each sonobuoy spacing. The geometry and sonobuoy spacing with the highest POD is selected as optimum.

Another computer simulation program, Search Tactics Evaluation Model (STEM) [Ref. 1] selects as optimum the pattern with the least number of gap areas inside which it is possible for the submarine to operate undetected.

C. THE SUBMARINE

The submarine is assumed to be making a straight-line transit on a course uniformly distributed between the limits of course accuracy (CUSACC), and with a mean of the expected submarine course (SUBCUS) in degrees true. The submarine's speed (SUBSPD) in knots remains constant throughout the transit.

D. INITIAL SUBMARINE PROBABILITY AREA

The initial submarine probability area is where the submarine is suspected to have been, at some fixed time in the past. It is datum. Realistically, the area may have any shape and size (i.e. diamond, circular, elliptical, rectangular, etc.), but for the purposes of this program it is assumed to be rectangular with no side longer than 1,000 nautical miles. The rectangle may be given any orientation, and the submarine position is assumed to be uniformly distributed inside.

E. SONOBUOY PATTERN AREA

The center of each potential sonobuoy pattern evaluated by NANCEE is at a single precomputed position. This position is on the submarine's expected line of transit far enough ahead of the submarine's position that all sonobuoys are in the water and being monitored before the submarine enters the pattern area. The sonobuoy patterns are all oriented perpendicular to the submarine's expected course and have a radius no larger than the extended radio-frequency range (see Appendix B). The GEOM subroutine prepares the initial submarine probability area and sonobuoy pattern area for simulation in the TOSS subroutine.

F. GENERATION OF 10 EQUALLY LIKELY DETECTION RANGES

On the average, the range at which a submarine will be detected from a sonobuoy is the mean-detection range (or the least range at which the target figure-of-merit intersects the propagation-loss curve). But it is seldom that the first detection occurs exactly at the mean-detection range. Sometimes the target is detected closer to the sonobuoy, sometimes further away. Recognizing this, the theory behind subroutine RANGE is that the propagation-loss curve varies

in accordance with a normal distribution with a standard deviation of SIGMA decibels. In turn, this randomly varying propagation-loss curve is used to generate RUNNR random detection ranges (see Appendix C).

From the RUNNR random detection ranges, ten are selected as equally likely representatives of the other random detection ranges. The random detection ranges are arranged in order from the smallest to the largest and then are counted in order starting with the smallest. The (0.1x1xRUNNR) th random detection range becomes the value of RANGES (I), where I varies from one to ten. It is intended that each element of the RANGES vector be close to the same length as one-tenth of the RUNNR random detection ranges, and therefore representative of them.

G. DISTRIBUTION OF SUBMARINE SIMULATION RUNS IN THE SONOBUOY PATTERN AREA

The size and shape of the initial submarine probability area along with time-late (TLATE) and the submarine's course accuracy (CUSACC) determine how submarine simulation runs originating from the initial submarine probability area are distributed in the potential sonobuoy pattern area. Knowledge of this distribution is essential in order to prudently evaluate potential sonobuoy positions.

To determine the distribution, the longest one-row sonobuoy pattern which has a spacing of BUOYSP nautical miles and still has a pattern radius less than ERFRNG nautical miles is centered in the sonobuoy pattern area. Each sonobuoy in this pattern is assumed to be continuously monitored with a detection range equal to the average detection range, RANGES (INDEX). NRTOSS submarine simulation

runs are sent through the sonobuoy pattern area. If the submarine is detected by a sonobuoy, that run is counted as a passage through a zone at that position in the pattern. There are NRBUOY sonobuoys in the pattern so there are NRBUOY zones through which passages can be detected. After the NRTOSS simulation runs, the number of passages through zone I (detections by sonobuoy number I) divided by NRTOSS equals DETECT (I), or the probability that a submarine will pass through zone I in the pattern. The TOSS subroutine generates this DETECT vector array.

Simulation runs which fail to pass through any sonobuoy pattern zone are assumed to be outside the detection range of the pattern and, thus, are impossible to detect. The number of those submarine simulation runs that do pass through the sonobuoy pattern area (i.e. $\sum_{I=1}^{NRBUOY}$ DETECT (I)) divided by NRTOSS is the probability a submarine will pass through the largest potential sonobuoy pattern area, and is an upper limit for the probability a submarine will be <u>detected</u> while passing through any possible pattern centered in the sonobuoy pattern area.

H. DETECTION WITHIN A ZONE

Not every submarine passing through a sonobuoy pattern zone will be detected. For instance, if the detection ranges fail to overlap, it is possible for the submarine to pass undetected between the buoys. Also, a submarine may pass through the detection range of a sonobuoy at a time when it is unmonitored.

In calculating the zone POD's, it is assumed that the submarine is on its expected course (SUBCUS), or a course perpendicular to the orientation of the sonobuoy pattern. As the submarine passes through a sonobuoy pattern zone, it will cross one of three sub-areas within that zone defined as follows:

Segment 1 - An area where the portion of the sonobuoy detection range which the submarine must transit is longer than the distance the submarine travels during the unmonitored portion of a monitor sequence (see Figure 3). Theoretically, the probability of detecting a submarine crossing through a segment 1 area is 1.0 (note: DIST1 is a segment 1 area in Figure 6).

Segment 2 - An area where the portion of the sonobuoy detection range which the submarine must transit is long enough to produce a minimum recognizable write-out, but less than the distance the submarine travels during the unmonitored portion of a monitor sequence (see Figure 3). The submarine may or may not be detected while passing through a segment 2 area depending on the success of the monitor sequence. Computation of these probabilities, p_Z, called meeting probabilities is described in Appendix D (note: DIST2 - DIST1 is a segment 2 area in Figure 6).

Segment 3 - An area where the portion of the sonobuoy detection range which the submarine must cross through is less than the distance the submarine travels in six minutes (see Figure 3). Theoretically, the submarine will fail to produce a recognizable write-out, so the probability of detecting a submarine crossing a segment 3 area is 0.0.

Variation of the number of rows and the sonobuoy detection range in a zone alters the distribution of segment 1, segment 2, and segment 3

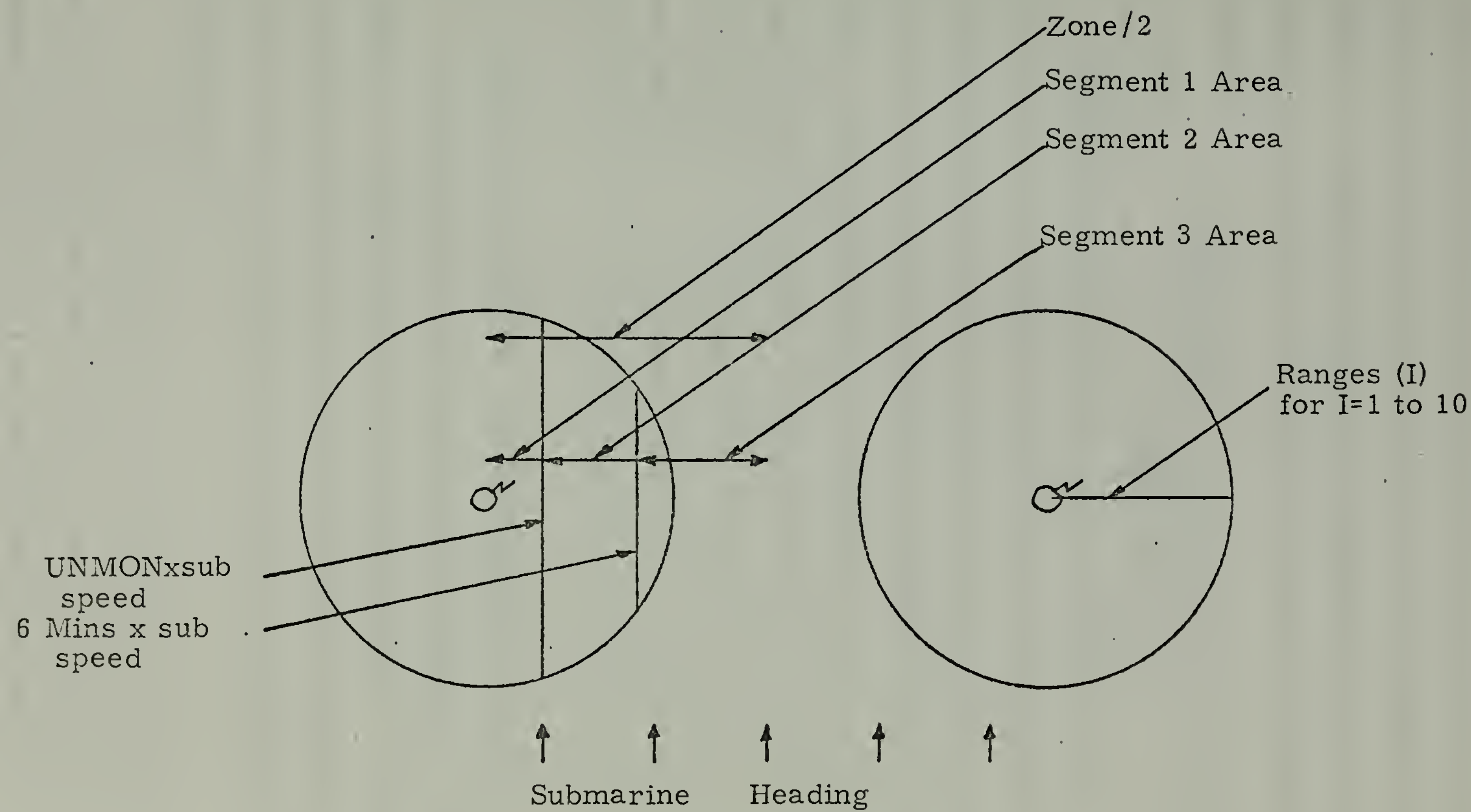

Figure 3

Segment 1, 2, and 3 Areas

areas within that zone. Similarly, variation of the monitor time and sequences per cycle alters the distribution because it changes the time sonobuoys are left unmonitored. If the sonobuoy detection range, number of sonobuoy pattern rows, and monitor plan are fixed for all sonobuoys in a zone, the POD for a submarine passing through that zone is,

$$\text{PROB} = \frac{1.0\text{x(segment 1)} + p_Z\text{x(segment 2)} + 0.0\text{x(segment 3)}}{\text{(zone length) / 2}}$$

PROB represents only one size of detection range. Recall, however, that earlier the generation of 10 equally likely detection ranges was discussed. Keeping the number of rows and the monitor plan fixed in a zone and computing PROB for each sized detection range, the sum divided by 10 is PD(I,J), or the probability an I row zone with each sonobuoy monitored using a J sequence monitor plan will detect the submarine (note: J equals one implies continuous monitoring). The purpose of the MEET subroutine is to generate the PD vector array for all combinations of I and J between one and three.

I. MONITOR SCHEMES FOR SONOBUOY PATTERNS

The monitoring aircraft is assumed to have a 16 channel monitor capacity. Consider and I row sonobuoy pattern. Which PD array element is appropriate in a zone of that pattern depends on how sonobuoys in that zone are monitored, or on which of the following four cases is appropriate:

Case 1 - There are 16 or fewer total sonobuoys in the pattern and the sonobuoy pattern radius is less than the radio-frequency range. Sonobuoys in all zones are considered to be continuously monitored, so POD in each zone is PD(I, 1).

Case 2 - There are between 17 and 32 total sonobuoys in the pattern and the sonobuoy pattern radius is less than the radio-frequency range. It is necessary to monitor sonobuoys in the pattern in two sequences. The zones extending inward from one side of the pattern containing a total of 16 sonobuoys comprise one sequence. Similarly, the zones extending inward from the other side of the pattern containing a total of 16 sonobuoys comprise the other sequence. With this arrangement, it is possible for zones toward the center of the sonobuoy pattern to belong to both sequences. Sonobuoys in these zones are considered to be continuously monitored, so POD in these zones is PD(I, 1). Sonobuoys in all other zones are affected by the two-sequence monitor plan and are considered to be monitored for BMON hours and then left unmonitored for UNMON(2) hours during each monitor cycle. POD in these zones is PD(I, 2).

Case 3 - There are more than 32 sonobuoys in the pattern and the sonobuoy pattern radius is less than the radio-frequency range. It is necessary to monitor sonobuoys in the pattern in three sequences. Two of the sequences are the same as was defined in case 2. The zones centered at pattern center and which contain a total of 16 sonobuoys comprise the third sequence. Sonobuoys in zones which belong to all three sequences are considered to be continuously monitored, so POD in these zones is PD(I, 1). Sonobuoys in zones which belong to two of the three sequences are considered to be monitored in accordance with the two sequence scheme of case 2, so POD in these zones is PD(I, 2). Finally, sonobuoys in zones which belong to only one sequence are considered to be monitored for BMON hours and left unmonitored for UNMON(3) hours during each monitor cycle, so POD in these zones is PD(I, 3).

Case 4 - The sonobuoy pattern radius is greater than the radio-frequency range. It is necessary to monitor sonobuoys in the pattern in three sequences (see Appendix B). The only difference between case 4 and case 3 is that in case 4, the number of sonobuoys per sequence is the total which fit inside the radio-frequency range, but which do not exceed a total of 16.

J. SONOBUOY PATTERN PROBABILITIES

The PD and DETECT vector arrays are the ingredients used to construct sonobuoy pattern probabilities in the BUILD subroutine.

DETECT(K) is the probability that a submarine will pass through zone K in the potential sonobuoy pattern area (where K is between 1 and NRBUOY). In comparison, PD(I, J) is the probability that if a submarine passes through any zone, an I row zone monitored using J sequences will detect the submarine. Hence,

$$p_K = PD(I, J) \times DETECT(K)$$

is the probability that the submarine will pass through zone K <u>and be detected.</u>

Construction of a sonobuoy pattern POD consists of:

1. Fixing the number of rows, I, in the pattern (between one and three).

2. Determining which zones the pattern will cover (centered in the potential sonobuoy pattern area). For example, N zones extending from zone z_1 to z_N.

3. Individually determining how each of the N zones in the sonobuoy pattern are to be monitored (which of the four cases in the previous section is appropriate for the pattern).

4. Summing p_K for each zone in the pattern, or

$$\text{PVEC}(I, N) = \sum_{K=z_1}^{z_N} p_K.$$

PVEC(I, N) is the POD of an I row pattern consisting of N zones. The total number of sonobuoys in this sonobuoy pattern is IxN.

K. SELECTION OF THE OPTIMUM PATTERN

The program builds POD's for all possible one, two, and three row sonobuoy patterns which have: A sonobuoy spacing equal to BUOYSP nautical miles, contain 48 or fewer sonobuoys, and which have a radius less than the extended radio-frequency range. The pattern with the highest POD (largest PVEC value) is selected as the optimum pattern. If more than one pattern has the highest POD, the one with the least total number of sonobuoys is selected as optimum.

IV. PROGRAM INPUTS AND OUTPUTS

A. INPUTS

The main program reads in values for program variables and arrays which require initialization. The read-in values are then tested to ensure they are within certain prescribed limits, and if not, the program is terminated. For a further description of program inputs see Appendix E.

B. NANCEE MAKEUP

Subroutine MAKEUP prints out the RANGES, DETECT, and PD vector arrays used to construct the sonobuoy pattern probabilities. This makes possible an in-depth analysis of the POD calculations. See Table I for an example of NANCEE MAKEUP.

C. NANCEE OUTPUT

Subroutine OUTPUT prints out:

1. All sonobuoy pattern descriptions and POD's which were considered in the selection of the optimum pattern. This section permits consideration of sonobuoy patterns which have POD's close to the POD of the optimum pattern, but which have fewer total sonobuoys.

2. Important program inputs (note: the propagation-loss heading information is a copy of the first two cards of Fleet Numerical Weather Central Monterey's propagation-loss curve data deck).

3. A description of the optimum pattern along with the optimum POD.

```
                                   NANCEE MAKEUP

RANGES ARRAY

     11.9
     11.9
     20.7
     20.7
     20.7
     20.7
     21.7
     22.2
     24.2
     32.1


DETECT ARRAY

  0.02800  0.04600   0.05800   0.04400   0.05200   0.04200   0.06600   0.03600   0.04600   0.04000
  0.04200


PC ARRAY      ROWS      SEQUENCES

   0.9629      1           1
   0.9550      1           2
   0.9124      1           3
   1.0000      2           1
   1.0000      2           2
   0.9772      2           3
   1.0000      3           1
   1.0000      3           2
   0.9866      3           3
```

TABLE I

An Example of NANCEE MAKEUP

and,

4. Optimum pattern orientation, spacing, location, and monitoring parameters.

See Table II for an example of NANCEE OUTPUT.

NANCEE OUTPUT

ROWS	SONOBUOYS	PO	ROWS	SONOBUOYS	PO	ROWS	SONOBUOYS	PO
1	1	0.0404	2	2	0.0420	3	3	0.0420
1	2	0.1040	2	4	0.1080	3	6	0.1080
1	3	0.1541	2	6	0.1600	3	9	0.1600
1	4	0.1887	2	8	0.1960	3	12	0.1960
1	5	0.2311	2	10	0.2400	3	15	0.2400
1	6	0.2754	2	12	0.2860	3	18	0.2860
1	7	0.3312	2	14	0.3440	3	21	0.3440
1	8	0.3697	2	16	0.3840	3	24	0.3840
1	9	0.4140	2	18	0.4300	3	27	0.4300
1	10	0.4545	2	20	0.4720	3	30	0.4720
1	11	0.4772	2	22	0.4974	3	33	0.4965

```
PROGRAM INPUTS

  PROPLOSS CURVE
  HEADING INFORMATION: 1MM26                             08  SRC AT    60 FT.  RCVR AT    60 FT.
                 DEPTH  4501 FT.  FREQ   .300 KHZ  SEA STATE  2                          740800Q0
  FIGURE-OF-MERIT:  95.6 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE:  25 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:  50 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=   10.0  X2=   10.0  X3=  -10.0  X4=  -10.0
                                      Y1=  -50.0  Y2=   50.0  Y3=   50.0  Y4=  -50.0
  TIME LATE: 12.5 HOURS
  AIRCRAFT ON-STATION SPEED: 180 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 20000 FEET


      OPTIMUM PATTERN: 2 ROWS  22 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.4974

   1*    2*    3*    4*    5*    6*    7*    8*    9*   10*   11*

     12*   13*   14*   15*   16*   17*   18*   19*   20*   21*   22*

OPTIMUM PATTERN PARAMETERS

  ORIENTATION: 115/295 DEGREES TRUE
  SONOBUOY SPACING:  29 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  376.7 NAUTICAL MILES/ 25 DEGREES TRUE
  USE 3 34 MINUTE MONITOR CYCLES
```

TABLE II
An Example of NANCEE OUTPUT

V. APPLICATIONS AND EXAMPLES

A. PROGRAM EXECUTION TIME

In the planning stages, it was hoped that NANCEE would execute in less than two minutes when the program reached its final form. In fact, the operating program substantially improves on this expectation. The average execution time with various input combinations has been 20 to 30 seconds. The most time consuming problems were those with small sonobuoy spacings (mini-barriers) because they generate a large number of sonobuoy pattern zones. For instance, one mini-barrier problem generated 43 zones and required 1 minute 9.88 seconds of execution time. Based on this testing, low execution time appears to be one of NANCEE's positive features.

B. NORMAL OPTIMUM PATTERN SELECTIONS

NANCEE normally selects a one or two-row sonobuoy pattern as optimum. The few times that a three-row pattern was selected, the increase in POD over the best two-row pattern was not significant.

C. THE MODE 2 PROGRAM FUNCTION

If MODE equals 1 (see Appendix E), the sonobuoy spacing (BUOYSP) is set internally to 1.41421xRANGES(INDEX). However, this spacing is not guaranteed to be the one that produces the maximum sonobuoy pattern POD. It is no more than a good logical estimate. By setting MODE to 2, it is possible to input sonobuoy spacing as well as sonobuoy monitor time per cycle by data card.

To illustrate the use of MODE 2, Tables III and IV are NANCEE MAKEUP and NANCEE OUTPUT for a problem executed in MODE 1. An exceptional POD of 0.9544 for a 3 row 21 sonobuoy pattern with a sonobuoy spacing of 48 nautical miles was found to be optimum. Some small detection ranges in the RANGES vector array of NANCEE MAKEUP indicated that a smaller sonobuoy spacing was worthy of consideration. Hence, a 20 nautical mile sonobuoy spacing was input using MODE 2. Tables V and VI are NANCEE MAKEUP and NANCEE OUTPUT for this MODE 2 case. The optimum pattern this time was a single row 13 sonobuoy pattern, which is nine sonobuoys less than the MODE 1 case. Notice, however, that the POD, although still an exceptional 0.938, is somewhat less than the MODE 1 POD.

D. PROPACATION -LOSS CURVE SHORTENING

Best results are obtained when the detection ranges generated in the RANGE subroutine are direct path ranges. Convergence zone ranges tend to inflate both the optimum pattern's POD and MODE 1 sonobuoy spacing. Usually convergence zones are found at distances greater than 30 nautical miles from a sonobuoy, so it is possible to chop off the portion of the propagation-loss curve past the first convergence zone (by reducing NPLPTS) thus forcing the program to only work with direct path ranges. Tables VII and VIII are NANCEE MAKEUP and NANCEE OUTPUT in a case where all 250 kiloyards of a propagation-loss curve with strong convergence zones was used (NPLPTS equals 250). The optimum sonobuoy pattern is a 2 row 12 sonobuoy pattern with a sonobuoy spacing of 57 nautical miles and a POD of 0.9582. Tables IX and X are NANCE MAKEUP and NANCEE

RANGES ARRAY

12.3
18.3
21.7
27.7
34.1
40.5
47.9
57.3
71.1
115.6

DETECT ARRAY

0.05000	0.17200	0.19000	0.20600	0.16800	0.10800	0.07200

PD ARRAY	ROWS	SEQUENCES
0.9177	1	1
0.8997	1	2
0.8306	1	3
1.0000	2	1
0.9798	2	2
0.8995	2	3
1.0000	3	1
0.9846	3	2
0.9236	3	3

TABLE III

NANCEE MAKEUP for MODE 1 Part of MODE 1/MODE 2 Comparison

NANCEE OUTPUT

ROWS	SONOBUOYS	PD
1	1	0.1907
1	2	0.3451
1	3	0.5194
1	4	0.6165
1	5	0.7764
1	6	0.8425
1	7	0.8727

ROWS	SONOBUOYS	PD
2	2	0.2080
2	4	0.3760
2	6	0.5660
2	8	0.6740
2	10	0.8460
2	12	0.9180
2	14	0.9501

ROWS	SONOBUOYS	PD
3	3	0.2080
3	6	0.3760
3	9	0.5660
3	12	0.6740
3	15	0.8460
3	18	0.9143
3	21	0.9544

```
PROGRAM INPUTS

  PROPLOSS CURVE
  HEADING INFORMATION: 19022                                  02  SRC AT    60 FT.  RCVR AT    60 FT.
                     DEPTH  1201 FT.  FREQ   .300 KHZ  SEA STATE  2                          74020000
  FIGURE-OF-MERIT:  75.2 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE: 124 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:  23 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=    5.0  X2=   45.0  X3=   -5.0  X4=  -45.0
                                      Y1=  105.0  Y2=   95.0  Y3= -105.0  Y4=  -95.0
  TIME LATE:  6.4 HOURS
  AIRCRAFT ON-STATION SPEED: 200 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 10000 FEET


OPTIMUM PATTERN: 3 ROWS  21 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.9544

 1*   2*   3*   4*   5*   6*   7*

   8*   9*  10*  11*  12*  13*  14*

 15*  16*  17*  18*  19*  20*  21*

OPTIMUM PATTERN PARAMETERS
  ORIENTATION:  34/214 DEGREES TRUE
  SONOBUOY SPACING:  48 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  286.8 NAUTICAL MILES/124 DEGREES TRUE
  USE 3 61 MINUTE MONITOR CYCLES
```

TABLE IV

NANCEE OUTPUT for MODE 1 Part of MODE 1/MODE 2 Comparison

NANCEE MAKEUP

```
RANGES ARRAY

     12.3
     18.3
     21.7
     27.7
     34.1
     40.5
     47.9
     57.3
     71.1
    115.6


DETECT ARRAY

  0.04400   0.08000   0.08800   0.06400   0.07400   0.11200   0.08200   0.08800   0.06000   0.09600
  0.05600   0.03600   0.05800


PC ARRAY     ROWS     SEQUENCES

   1.0000     1         1
   1.0000     1         2
   1.0000     1         3
   1.0000     2         1
   1.0000     2         2
   1.0000     2         3
   1.0000     3         1
   1.0000     3         2
   1.0000     3         3
```

TABLE V

NANCEE MAKEUP for MODE 2 Part of MODE 1/MODE 2 Comparison

ROWS	SONOBUOYS	PO	ROWS	SONOBUOYS	PO	ROWS	SONOBUOYS	PO
1	1	0.0820	2	2	0.0820	3	3	0.0820
1	2	0.1700	2	4	0.1700	3	6	0.1700
1	3	0.2820	2	6	0.2820	3	9	0.2820
1	4	0.3420	2	8	0.3420	3	12	0.3420
1	5	0.4160	2	10	0.4160	3	15	0.4160
1	6	0.5120	2	12	0.5120	3	18	0.5120
1	7	0.5760	2	14	0.5760	3	21	0.5760
1	8	0.6320	2	16	0.6320	3	24	0.6320
1	9	0.7200	2	18	0.7200	3	27	0.7200
1	10	0.7560	2	20	0.7560	3	30	0.7560
1	11	0.8360	2	22	0.8360	3	33	0.8360
1	12	0.8940	2	24	0.8940	3	36	0.8940
1	13	0.9380	2	26	0.9380	3	39	0.9380

```
PROGRAM INPUTS

  PROPLOSS CURVE
  HEADING INFORMATION: 1R022                                          02  SRC AT    60 FT.  RCVR AT    60 FT.
                     DEPTH  1201 FT.  FREQ   .300 KHZ  SEA STATE  2                              74020000
  FIGURE-OF-MERIT:  75.2 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE: 124 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:  23 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=    5.0  X2=    45.0  X3=   -5.0  X4=   -45.0
                                      Y1=  105.0  Y2=    95.0  Y3= -105.0  Y4=   -95.0
  TIME LATE:  6.4 HOURS
  AIRCRAFT ON-STATION SPEED: 200 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 10000 FEET


         OPTIMUM PATTERN: 1 ROWS  13 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.9380


  1*    2*    3*    4*    5*    6*    7*    8*    9*    10*    11*    12*    13*


OPTIMUM PATTERN PARAMETERS

  ORIENTATION:  34/214 DEGREES TRUE
  SONOBUOY SPACING:  20 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  266.8 NAUTICAL MILES/124 DEGREES TRUE
  MONITOR ALL PATTERN SONOBUOYS CONTINUOUSLY
```

TABLE VI

NANCEE OUTPUT for MODE 2 Part of MODE 1/MODE 2 Comparison

NANCEE MAKEUP

RANGES ARRAY

12.8
20.2
39.5
40.0
41.0
41.5
42.5
77.0
80.5
119.5

DETECT ARRAY

0.06400	0.21000	0.24000	0.20800	0.16800	0.07800

PC ARRAY	ROWS	SEQUENCES
0.9159	1	1
0.9052	1	2
0.8681	1	3
0.9898	2	1
0.9760	2	2
0.9278	2	3
0.9898	3	1
0.9801	3	2
0.9462	3	3

TABLE VII

NANCEE MAKEUP for Propagation-Loss Curve Shortening Example - NPLPTS = 250

NANCEE OUTPUT

ROWS	SONOBUOYS	PD	ROWS	SONOBUOYS	PD	ROWS	SONOBUOYS	PD
1	1	0.2190	2	2	0.2376	3	3	0.2376
1	2	0.4103	2	4	0.4434	3	6	0.4434
1	3	0.6026	2	6	0.6513	3	9	0.6513
1	4	0.7565	2	8	0.8176	3	12	0.8176
1	5	0.8151	2	10	0.8809	3	15	0.8809
1	6	0.8860	2	12	0.9582	3	18	0.9568

```
PROGRAM INPUTS
  PROPLOSS CURVE
  HEADING INFORMATION: 1A103                                  02  SRC AT    60 FT.  RCVR AT     60 FT.
                       DEPTH 14400 FT.  FREQ   .300 KHZ  SEA STATE  2                              74020000
  FIGURE-OF-MERIT:  88.2 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE: 124 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:  23 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=    5.0  X2=    45.0  X3=   -5.0  X4=  -45.0
                                      Y1=  105.0  Y2=    95.0  Y3= -105.0  Y4=  -95.0
  TIME LATE:  6.4 HOURS
  AIRCRAFT ON-STATION SPEED: 180 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 20000 FEET

OPTIMUM PATTERN: 2 ROWS  12 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.9582

1*    2*    3*    4*    5*    6*

   7*    8*    9*    10*   11*   12*

OPTIMUM PATTERN PARAMETERS
  ORIENTATION:  34/214 DEGREES TRUE
  SONOBUOY SPACING:  57 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  303.0 NAUTICAL MILES/124 DEGREES TRUE
  MONITOR ALL PATTERN SONOBUOYS CONTINUOUSLY
```

TABLE VIII

NANCEE OUTPUT for Propagation-Loss Curve Shortening Example - NPLPTS = 250

NANCEE MAKEUP

RANGES ARRAY

9.4
10.4
11.4
12.3
13.6
14.8
15.8
18.3
20.7
29.1

DETECT ARRAY

0.02400	0.05600	0.07000	0.07400	0.05600	0.08000	0.08800	0.09600	0.06600	0.05400
0.06600	0.06200	0.06000	0.02400	0.03400					

PC ARRAY	ROWS	SEQUENCES
0.9982	1	1
0.9960	1	2
0.9837	1	3
1.0000	2	1
1.0000	2	2
1.0000	2	3
1.0000	3	1
1.0000	3	2
1.0000	3	3

TABLE IX

NANCEE MAKEUP for Propagation-Loss Curve Shortening Example - NPLPTS = 71

ROWS	SONOBUOYS	PD	ROWS	SONOBUOYS	PD	ROWS	SONOBUOYS	PD
1	1	0.0958	2	2	0.0960	3	3	0.0960
1	2	0.1617	2	4	0.1620	3	6	0.1620
1	3	0.2496	2	6	0.2500	3	9	0.2500
1	4	0.3035	2	8	0.3040	3	12	0.3040
1	5	0.3833	2	10	0.3840	3	15	0.3840
1	6	0.4492	2	12	0.4500	3	18	0.4500
1	7	0.5051	2	14	0.5060	3	21	0.5060
1	8	0.5670	2	16	0.5680	3	24	0.5680
1	9	0.6408	2	18	0.6420	3	27	0.6420
1	10	0.7007	2	20	0.7020	3	30	0.7020
1	11	0.7706	2	22	0.7720	3	33	0.7720
1	12	0.7946	2	24	0.7960	3	36	0.7960
1	13	0.8505	2	26	0.8520	3	39	0.8520
1	14	0.8844	2	28	0.8660	3	42	0.8860
1	15	0.9073	2	30	0.9100	3	45	0.9100

PROGRAM INPUTS

```
  PROPLOSS CURVE
  HEADING INFORMATION: 1A103                                        02  SRC AT     60 FT.  RCVR AT     60 FT.
           DEPTH 14400 FT.  FREQ    .300 KHZ  SEA STATE  2                                             74020000
  FIGURE-OF-MERIT:  86.2 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE: 124 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:   23 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=    5.0  X2=   45.0  X3=   -5.0  X4=  -45.0
                                      Y1=  105.0  Y2=   95.0  Y3= -105.0  Y4=  -95.0

  TIME LATE:  6.4 HOURS
  AIRCRAFT ON-STATION SPEED: 180 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 20000 FEET
```

OPTIMUM PATTERN: 2 ROWS 30 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.9100

```
1*   2*   3*   4*   5*   6*   7*   8*   9*   10*  11*  12*  13*  14*  15*

  16*  17*  18*  19*  20*  21*  22*  23*  24*  25*  26*  27*  28*  29*  30*
```

OPTIMUM PATTERN PARAMETERS

```
  ORIENTATION:  34/214 DEGREES TRUE
  SONOBUOY SPACING:  19 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  282.2 NAUTICAL MILES/124 DEGREES TRUE
  USE 3 19 MINUTE MONITOR CYCLES
```

TABLE X

NANCEE OUTPUT for Propagation-Loss Curve Shortening Example - NPLPTS = 71

OUTPUT for a problem with identical inputs except NPLPTS has been reduced to 71 to exclude all convergence zones. The optimum sonobuoy pattern this time is a 2 row 30 sonobuoy pattern with an 18 nautical mile sonobuoy spacing and a POD reduced somewhat to 0.91. The pattern computed without convergence zones will produce more reliable results.

E. PROPAGATION-LOSS CURVES WITH ZIG-ZAG PATTERNS

For the same reason that propagation-loss curves with strong convergence zones can cause problems, propagation-loss curves with zig-zag patterns (curves which alternate radically between high and low decibel levels) can also be a problem. An extreme example of this was input to test the program. NANCEE MAKEUP and NANCEE OUTPUT in Tables XI and XII appear to be quite reasonable solutions to the problem. Randomization of IRANGE (see Appendix C) deserves credit for this success.

F. A COMPARISON WITH TASDA AC

NANCEE and TASDA AC [Ref. 2] were programmed with identical inputs to form a comparison between the two programs. NANCEE MAKEUP and NANCEE OUTPUT for the comparison are in Tables XIII and XIV.

NANCEE selected a 2 row 12 sonobuoy pattern with a sonobuoy spacing of 30 nautical miles as optimum. TASDA AC, programmed to consider 10 geometries and using 20 submarine simulation runs per probability calculation, selected a box-shaped pattern with 16 sonobuoys and a 57 nautical mile spacing.

NANCEE MAKEUP

RANGES ARRAY

6.9
13.8
13.8
14.3
27.7
27.7
41.5
41.5
57.3
110.1

DETECT ARRAY

0.04400	0.14400	0.13600	0.18800	0.14800	0.13600	0.09200	0.06400

PD ARRAY	ROWS	SEQUENCES
0.8498	1	1
0.8189	1	2
0.7351	1	3
C.9702	2	1
C.9409	2	2
0.8374	2	3
C.9702	3	1
0.9495	3	2
0.8769	3	3

TABLE XI

NANCEE MAKEUP for Zig-Zag Pattern Example

NANCEE OUTPUT

ROWS	SONOBUOYS	PD
1	1	0.1596
1	2	0.2855
1	3	0.4011
1	4	0.5167
1	5	0.6390
1	6	0.7172
1	7	0.7546
1	8	0.7693

ROWS	SONOBUOYS	PD
2	2	0.1824
2	4	0.3260
2	6	0.4579
2	8	0.5899
2	10	0.7296
2	12	0.8188
2	14	0.8615
2	16	0.9024

ROWS	SONOBUOYS	PD
3	3	0.1824
3	6	0.3260
3	9	0.4579
3	12	0.5899
3	15	0.7296
3	18	0.8139
3	21	0.8529
3	24	0.8963

```
PROGRAM INPUTS

  PROPLOSS CURVE                                                 02  SRC AT     60 FT.  RCVR AT      60 FT.
  HEADING INFORMATION: 1MK26
                          DEPTH   4501 FT.   FREQ    .300 KHZ   SEA STATE  2                         74020000
  FIGURE-OF-MERIT:  75.2 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE: 124 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:  23 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=     5.0  X2=    45.0  X3=    -5.0  X4=   -45.0
                                      Y1=   105.0  Y2=    95.0  Y3=  -105.0  Y4=   -95.0

  TIME LATE:  6.4 HOURS
  AIRCRAFT ON-STATION SPEED: 200 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 10000 FEET


OPTIMUM PATTERN: 2 ROWS  16 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.9024

   1*   2*   3*   4*   5*   6*   7*   8*

     9*   10*   11*   12*   13*   14*   15*   16*

OPTIMUM PATTERN PARAMETERS

  ORIENTATION:  34/214 DEGREES TRUE
  SONOBUOY SPACING:  37 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  281.1 NAUTICAL MILES/124 DEGREES TRUE
  MONITOR ALL PATTERN SONOBUOYS CONTINUOUSLY
```

TABLE XII

NANCEE OUTPUT for Zig-Zag Pattern Example

NANCEE MAKEUP

RANGES ARRAY

0.0
9.4
10.9
11.9
21.7
22.2
22.2
25.2
43.5
110.1

DETECT ARRAY

0.0	0.0	0.04200	0.22400	0.25600	0.24000	0.20400	0.03400	0.0	0.0

PD ARRAY	ROWS	SEQUENCES
0.8150	1	1
0.7966	1	2
0.7203	1	3
0.9000	2	1
0.8956	2	2
0.8098	2	3
0.9000	3	1
0.8958	3	2
0.8373	3	3

TABLE XIII

NANCEE MAKEUP for TASDA AC Comparison

NANCEE OUTPUT

ROWS	SONOBUOYS	PD	ROWS	SONOBUOYS	PD	ROWS	SONOBUOYS	PD
1	1	0.2081	2	2	0.2304	3	3	0.2304
1	2	0.4033	2	4	0.4464	3	6	0.4464
1	3	0.5854	2	6	0.6480	3	9	0.6480
1	4	0.7513	2	8	0.8316	3	12	0.8316
1	5	0.7854	2	10	0.8694	3	15	0.8694
1	6	0.8130	2	12	0.9000	3	18	0.9000
1	7	0.8130	2	14	0.9000	3	21	0.9000
1	8	0.8130	2	16	0.9000	3	24	0.8999
1	9	0.8130	2	18	0.9000	3	27	0.8999
1	10	0.8130	2	20	0.9000	3	30	0.8998

```
PROGRAM INPUTS
  PROPLOSS CURVE                                                   05   SRC AT    60 FT.   RCVR AT    300 FT.
  HEADING INFORMATION: 1B144                                                                        74050000
                        DEPTH  8625 FT.   FREQ   .050 KHZ   SEA STATE  3
  FIGURE-OF-MERIT:  85.0 DB
  SUBMARINE SPEED: 20 KNOTS
  SUBMARINE COURSE:    0 DEGREES TRUE
  SUBMARINE COURSE ACCURACY:  20 DEGREES EITHER SIDE OF COURSE
  INITIAL SUBMARINE PROBABILITY AREA: X1=   10.0  X2=   10.0  X3=  -10.0  X4=  -10.0
                                      Y1=  -50.0  Y2=   50.0  Y3=   50.0  Y4=  -50.0
  TIME LATE:  3.3 HOURS
  AIRCRAFT ON-STATION SPEED: 180 KNOTS
  AIRCRAFT ON-STATION ALTITUDE: 20000 FEET

OPTIMUM PATTERN: 2 ROWS  12 SONOBUOYS - PROBABILITY-OF-DETECTION= 0.9000

 1*   2*   3*   4*   5*   6*

   7*   8*   9*   10*   11*   12*

OPTIMUM PATTERN PARAMETERS
  ORIENTATION:  90/270 DEGREES TRUE
  SONOBUOY SPACING:  30 NAUTICAL MILES
  RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CENTER TO SONOBUOY PATTERN CENTER:  193.5 NAUTICAL MILES/  0 DEGREES TRUE
  MONITOR ALL PATTERN SONOBUOYS CONTINUOUSLY
```

TABLE XIV

NANCEE OUTPUT for TASDA AC Comparison

Both NANCEE and TASDA AC estimated the optimum pattern POD as 0.9. However, to compute these results TASDA AC executed in 1 minute and NANCEE executed in 20.89 seconds (with NRUNS and NRTOSS preset to 500).

The same program inputs were used again with TASDA AC except, this time, the number of submarine simulation runs for each probability calculation was increased to 50. Four optimum patterns were selected and each pattern's POD was near 0.95. The program execution time increased to 4 minutes 33.73 seconds.

VI. CONCLUSIONS

A. PROGRAM EFFECTIVENESS

NANCEE is well suited to determine which barrier type of sonobuoy pattern has the highest POD for a transiting nuclear submarine. The program executes rapidly, incorperates a high degree of realism, and is easy to use and understand. NANCEE MAKEUP and NANCEE OUTPUT are designed to provide sufficient program details to capitalize on the built-in flexibility of the MODE 1 and MODE 2 program functions.

B. COMPUTER REQUIREMENTS

Since NANCEE is coded in FORTRAN IV, the program must be used on computers equipped with a FORTRAN IV compiler. It is possible to convert NANCEE to the UNIVAC assembler language used in Tactical Support Center computers, but unfortunately, the program requires too much core to be used in the current P3C computer configuration. However, a proposed auxilliary drum storage addition to that computer would increase storage capacity sufficiently and make airborne use of the program feasible.

C. RECOMMENDATIONS FOR FUTURE EFFORT

Future effort with this program should be directed towards increasing program realism. Specifically, an adaption of the program to consider random monitor sequence disruption would be a significant

improvement. It is also feasible to adapt the program to consider random snorkel cycles (and therefore be appropriate for diesel submarines).

NANCEE is not intended to solve either holding or tracking submarine problems (see Chapter I). In fact, it is questionable whether the type of approach used in NANCEE is adaptable to these types of problems. Other computer programs such as TASDA and STEM can be used in these cases.

APPENDIX A

RADIO-FREQUENCY RANGE

The aircraft's altitude (ACALT), in feet, is used to compute the maximum radio-frequency rangc (RFRNG) in nautical miles. The formula,

$$RFRNG = 1.064 \sqrt{ACALT},$$

defines this relationship. As ACALT increases, RFRNG also increases to an upper limit of about 120 nautical miles. No further increase is possible because of signal attenuation.

APPENDIX B

EXTENDED RADIO-FREQUENCY RANGE

The question of how large a sonobuoy pattern radius can be and still ensure adequate monitoring of all pattern sonobuoys is crucial. Obviously, if all pattern sonobuoys are within RFRNG of the center of the pattern, and if the aircraft orbits the center of the pattern, all sonobuoys are immediately available for monitoring no matter what monitor plan is chosen.

However, the radius of the pattern may be increased over RFRNG by capitalizing on the time sonobuoys will be left unmonitored during a monitor cycle. To demonstrate this, note that the aircraft can fly CYCLE(I)xACSPD nautical miles during an I sequence monitor cycle. Only one-half of that distance ((CYCLE(I)xACSPD)/2) can be flown starting at and returning to the same position. If half of that distance is distributed on one side of the pattern center and the other half on the other side, it appears that the sonobuoy pattern radius may be increased by,

$$\frac{\mathrm{CYCLE(I)xACSPD}}{4} = \frac{\mathrm{IxBMONxACSPD}}{4} \quad \text{nautical miles,}$$

Recall, however, that all pattern sonobuoys are to be monitored for a minimum of BMON hours per monitor cycle. With a pattern width of

$$\mathrm{RFRNG} + \frac{\mathrm{IxBMONxACSPD}}{4} \quad \text{nautical miles,}$$

the sonobuoys farthest from pattern center fail to be monitored sufficiently. To correct this, the pattern radius should be reduced by $\frac{\mathrm{BMONxACSPD}}{2}$ nautical miles.

Based on this, a two-sequence monitor plan (I equals two) yields a maximum sonobuoy pattern radius of,

$$\text{RFRNG} + \frac{2\text{xBMONxACSPD}}{4} - \frac{\text{BMONxACSPD}}{2} = \text{RFRNG nautical miles.}$$

This leads to the unexpected conclusion that a two-sequence monitor plan allows a pattern radius only as large as RFRNG.

In comparison, a three sequence conitor plan (I equals three) yields a maximum pattern radius of,

$$\text{RFRNG} + \frac{3\text{xBMONxACSPD}}{4} - \frac{\text{BMONxACSPD}}{2}$$

$$= \text{RFRNG} + \frac{\text{BMONxACSPD}}{4} \text{ nautical miles.}$$

Hence, RFRNG + $\frac{\text{BMONxACSPD}}{4}$ nautical miles is the extended radio-frequency range (ERFRNG) if a three sequence monitor plan is used.

APPENDIX C

GENERATION OF RANDOM DETECTION RANGES

As stated in Chapter III, the theory behind subroutine RANGE is that the propagation-loss curve varies in accordance with a normal distribution with a standard deviation of SIGMA decibels. In turn, this randomly varying propagation-loss curve is used to generate RUNNR random detection ranges.

Although it is theoretically correct to vary the propagation-loss curve and hold the figure-of-merit constant, in practice it involves far less numerical computations to use the opposite but equivalent procedure of holding the propagation-loss curve constant and varying the figure-of-merit normally. This is accomplished by using SIGMA and twelve uniform (O, 1) random numbers, RN, to compute a random figure-of-merit deviation, FOMDEV, or

$$\text{FOMDEV} = \text{SIGMAx}\left(\sum_{I=1}^{12} \text{RN}_I - 6.0\right).$$

TEMPFM equals FOM + FOMDEV, and is a normally distributed random figure-of-merit with a mean of FOM and standard deviation of SIGMA.

A detection is defined to have occurred at a specified range from the sonobuoy where TEMPFM is larger than the value of the propagation-loss curve at that range. In a simulation run, a uniformly random range, IRANGE, between O and NPLPTS is selected. If the target is

detected at this first setting of IRANGE, that simulation run is disregarded. Otherwise, IRANGE is decreased in one-kiloyard increments until a detection occurs. In this manner, after NRUNS simulation runs, RUNNR random detection ranges are generated.

APPENDIX D

CALCULATION OF MEETING PROBABILITIES

Segment 2 was defined in Chapter III to be an area within a sonobuoy pattern zone for which the portion of the sonobuoy detection range a submarine must cross through is long enough to produce a minimum recognizable write-out, but less than the distance the submarine travels during the unmonitored portion of a monitor sequence. The POD of a submarine crossing a segment 2 area, p_Z, depends upon the success of the monitor cycle, and can be described as a meeting probability.

To compute these probabilities, consider an I sequence monitor cycle of CYCLE(I) hours with a monitor time of BMON hours per cycle and an unmonitor time of UNMON(I) hours per cycle (where I equals two or three). A submarine will be within detection range of a sonobuoy in a segment 2 area for an average time of t hours, where (6 minutes $<$ t $<$ UNMON (I). Since t is less than UNMON(I), t must also be less than CYCLE(I). Therefore, the critical cycle in the computation of p_Z is the one during which the submarine passes through the sonobuoy detection range. If the start of monitoring (s) is allowed to vary uniformly between the start and end of a cycle (or from O to CYCLE(I) hours) and, likewise, the entrance of the submarine into the sonobuoy's detection range (e) is varied uniformly between the start and end of the cycle, those cases where BMON and t overlap are defined to mean that a detection has occurred. If BMON and t do <u>not</u> overlap, there is no detection. The determination of the meeting probability for one

sonobuoy in a zone, then, is an equivalent problem to the determination of the probability that t and BMON overlap.

The problem is divided into two cases:

Case 1 - The start of monitoring, s, occurs before the entrance of the submarine into the sonobuoy's detection range, e.

and,

Case 2 - The submarine enters the sonobuoy's detection range, e, before the start of monitoring, s.

For Case 1, a detection (overlap) occurs if $s - e < BMON$. Similarly, for Case 2, a detection occurs if $e - s < t$. These equations are plotted in Figure 4. Inside the square of Figure 4, the shaded area is the area where an overlap will occur, and hence, is the area where the submarine will be detected. The unshaded area is the area where no detection will occur. The shaded area divided by the area of the square (i.e. $CYCLE(I)^2$) is p_S, the probability a sonobuoy monitored BMON hours per cycle, with I sequences per cycle, will detect a submarine passing through a segment 2 area of a zone.

Depending upon the number of rows in a sonobuoy pattern zone, there may be more than one sonobuoy in that zone with a segment 2 area. Fortunately, for a given sonobuoy detection range, if more than one sonobuoy has a segment 2 area, each has the same average detection-range-crossing-time, t. Hence the meeting probabilities, p_S, for each of the sonobuoys are the same. Prior to the first detection, sonobuoy detections are independent events and can be thought of as independent Bernoulli trials. The probability that at least one of n sonobuoys, in a segment 2 area of a zone will detect the submarine, is the following sum of binomial probabilities:

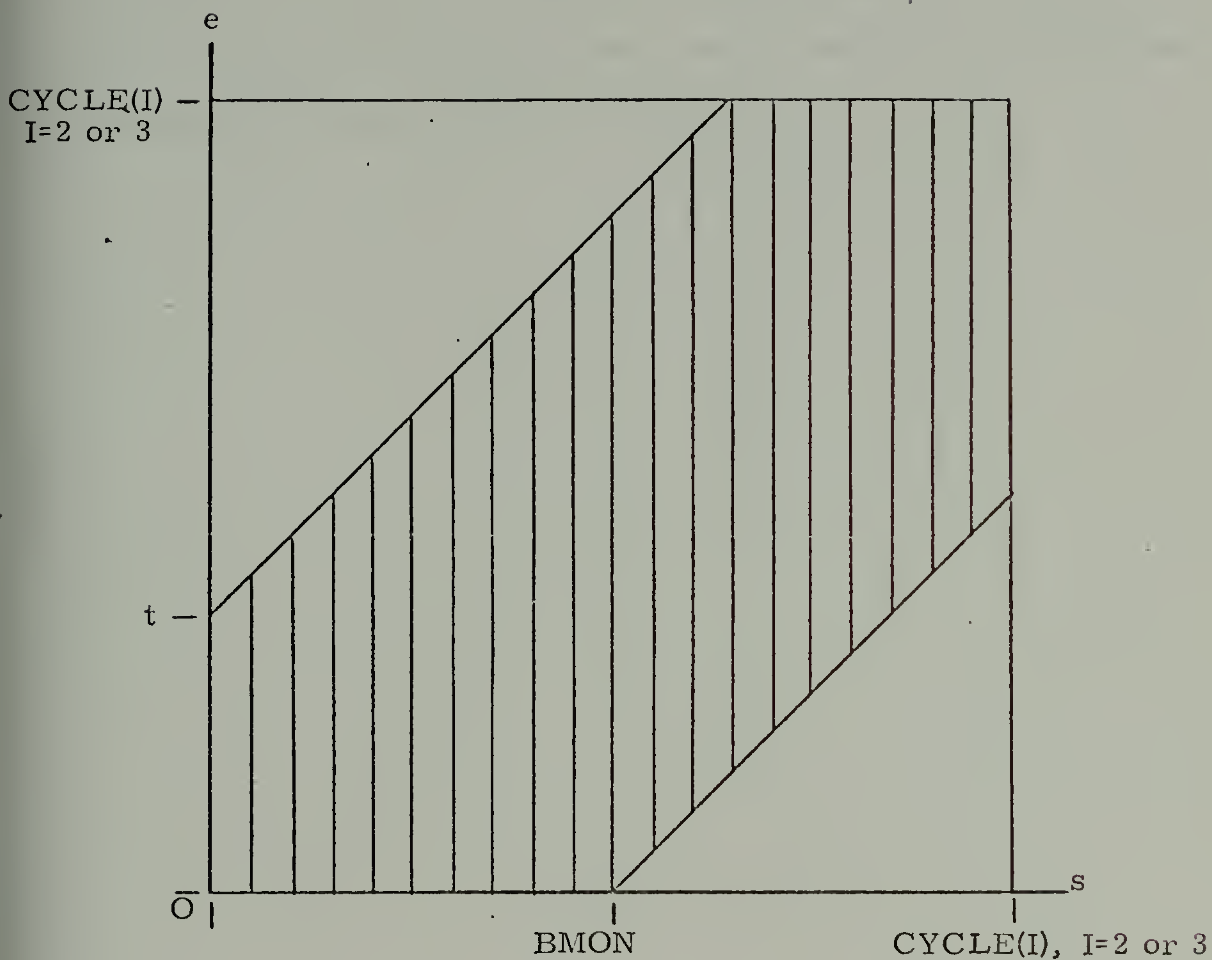

Figure 4

Meeting Probability Graph

$$p_Z = \sum_{I=1}^{n} \binom{n}{I} x (p_S)^I x (1 - p_S)^{n-I}.$$

p_Z is the Segment 2 meeting probability for the zone.

It must be noted that the discussion above is somewhat simplified in an attempt to make the idea of meeting probability clear. Actual segment 2 areas are the DISTM1 and DISTM2 spanned areas of Figures 7, 8, and 9. The average crossing distances through these areas are HTM1 and HTM2 respectively.

APPENDIX E

PROGRAM INPUTS

Table XV lists the variables and arrays that require initialization in the program, along with their associated data card number, range, and meaning (also, recall that Appendix F contains more comprehensive definitions of all major program variables and arrays).

In amplification of Table XV, if MODE equals 2, IBOYSP and IBMON are input to the program on data card number 1a. However, if MODE equals 1, IBOYSP and IBMON are computed in subroutine GEOM and card 1a must not be included in the data deck.

Furthermore, as stated in Chapter III, the initial submarine probability area must be a rectangle and it is input to the program by virtue of data card number 4. (X1, Y1) and (X2, Y2) are any two distinct, adjacent corners of the initial submarine probability area (i.e. at opposite ends of a common side of the rectangle).

Finally, data cards 7 through 33 contain propagation-loss curve heading information followed by the propagation-loss curve in decibels discretized into one-kiloyard increments. The number of one-kiloyard increments used by the program out to a maximum of 250 kiloyards is specified by NPLPTS. Normally it should not be necessary to keypunch any of cards 7 through 33. Instead, it is intended that they be punched by Fleet Numerical Weather Central Monterey's passive sonar prediction program.

Data Card Nr	Variable/Array	Units	Range	Meaning
1	MODE	-	1 or 2	Program MODE
1a	IBOYSP	NM	4 - 200	sonobuoy spacing
1a	IBMON	Mins	10 - 60	sonobuoy monitor time per sequence
2	IACSPD	KTS	120 - 350	on-station aircraft speed
2	IACALT	FT	100 - 30,000	on-station aircraft altitude
3	ISUBSPD	KTS	3 - 50	estimated submarine speed
3	ISUBCUS	DEG T	000 - 360	estimated submarine course
3	ICUSAC	DEG	000 - 180	estimated submarine course accuracy
4	X1	NM	no side of	(X1, Y1) and (X2, Y2)
4	Y1	NM	initial sub-	are adjacent corners
4	X2	NM	marine prob-	of the initial submarine
4	Y2	NM	ability area	probability area.
			longer than 1000NM	
5	TLATE	HRS	0 - 48	time late
6	FOM	DB	0 - 220	figure-of-merit
6	NPLPTS	Kiloyards	0 - 250	number of propagation-loss points
7, 8	IDATA-(Array)	-	-	propagation-loss curve identification data
9-33	PLOSS-(Array)	DB	0 - 220	propagation-loss curve

TABLE XV

Program Inputs

APPENDIX F

LIST OF MAJOR PROGRAM VARIABLES AND ARRAYS

ACALT - The aircraft's on-station altitude in feet above sea level.

ACSPD - The aircraft's on-station speed in knots.

ALFA - See Figure 5.

AX1 - Absolute value of X1.

AX2 - Absolute value of X2.

AY1 - Absolute value of Y1.

AY2 - Absolute value of Y2.

BMON - The sonobuoy monitor-time-per-sequence, in hours.

BSUM - Used to generate the vector array PY. It is varied from 0 to 2.0xSHIFT in increments of BUOYSP.

BUOYD - In the TOSS subroutine, the distance from the current submarine position (TEMPX, TEMPY) to the sonobuoy positions (PCX, PY(I)), where I varies from 1 to NRBUOY.

BUOYSP - The sonobuoy pattern spacing in nautical miles.

CIRMAX - The maximum distance, in nautical miles, from the center of the sonobuoy pattern area at which a detection can be expected. CIRMAX = RANGES (INDEX) + SHIFT.

CUSACC - The maximum angle in degrees that the submarine is expected to deviate to either side of its projected course.

CYCLE(I) - If a sonobuoy pattern is monitored with I sequences per cycle, where I equals two or three, CYCLE(I) is the time in hours to complete one cycle.

DETECT(I) - A vector array containing the probabilities that a submarine will pass through sonobuoy pattern zone I, where I varies from 1 to NRBUOY.

DETS(I) - A vector array containing the number of detections which occurred at range I in the RANGE subroutine, where I varies from 1 to NPLPTS.

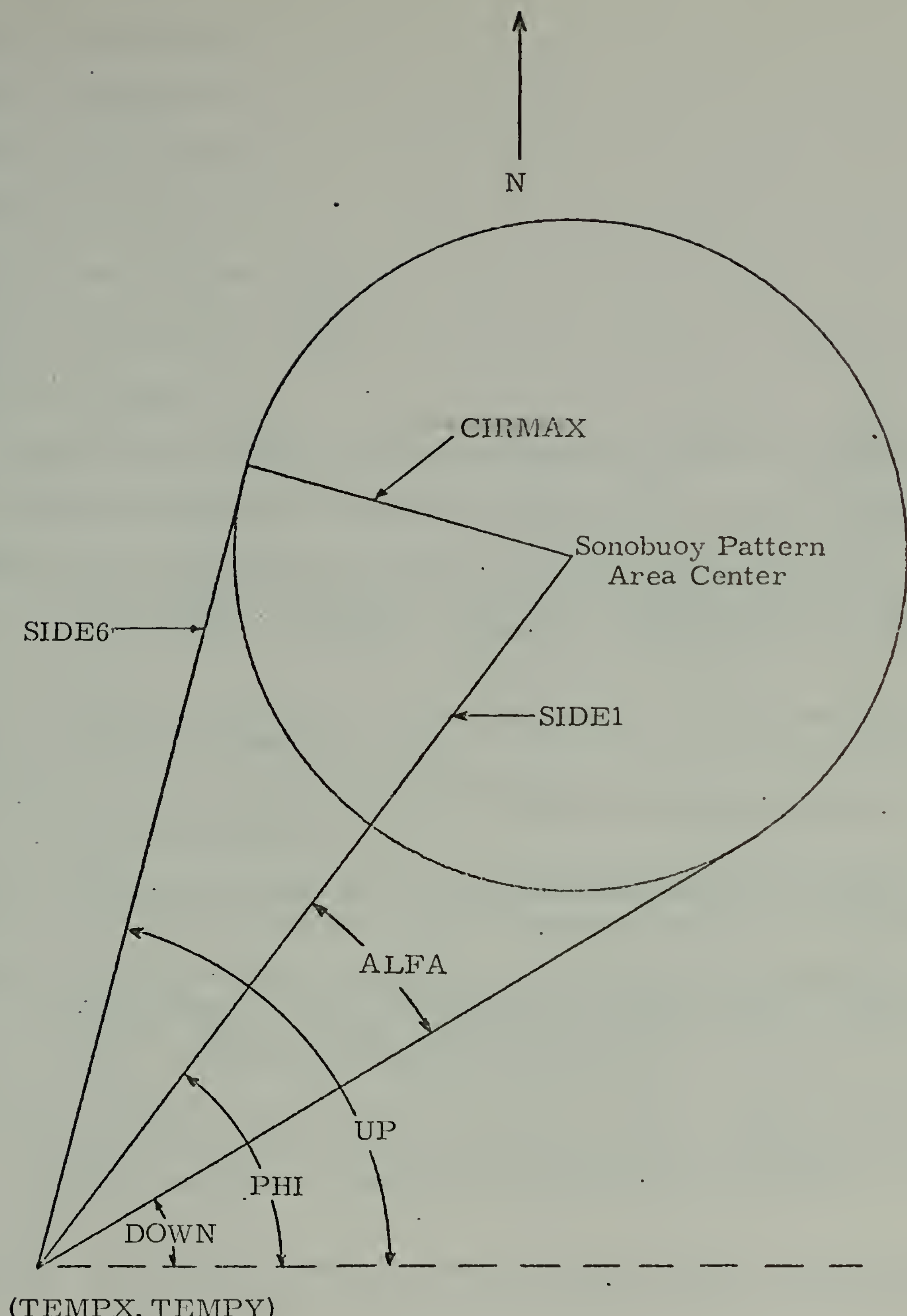

Figure 5

Geometry used to Calculate Whether TEMCUS Penetrates Sonobuoy Pattern Detection Range

DIST1 - See Figure 6.

DIST2 - See Figure 6.

DISTB - See Figure 8.

DISTI - See Figure 10.

DISTM1 - See Figures 7 and 8.

DISTM2 - See Figures 8 and 9.

DOWN - See Figure 5.

DX - One-half the distance between the points (XO, YO) and (XP, YP).

DY - One-half the distance between the points (-XO, -YO) and (XP, YP).

ERFRNG - The extended radio-frequency range if a three sequence monitor plan is used, with a sonobuoy monitor time per cycle of BMON. ERFRNG = $\text{RFRNG} + \frac{\text{BMONxACSPD}}{4}$ (see Appendix B).

FILL1 - A working variable set to 0.05xSUBSPD to avoid unnecessary repeat calculations.

FILL2 - A working variable set to SPACE/2.0 to avoid unnecessary repeat calculations.

FILL3 - A working variable set to (UNMON(I)xSUBSPD)/2.0, where I equals two or three, to avoid unnecessary repeat calculations.

FLAG - A logical variable used during the computation of pattern probabilities. For a fixed number of pattern rows, FLAG equals .FALSE. until the first occurrence of a three sequence monitor cycle. Thereafter, FLAG equals .TRUE..

FOM - The figure-of-merit of the submarine target. FOM equals SL - AN -RD, where SL is the target source level, AN is the ocean ambient noise level, and RD is the operator recognition differential.

FOMDEV - The figure-of-merit deviation computed as a random normal deviation about a mean of zero and a standard deviation of SIGMA.

GAMMA - The angle to which the point (RX, RY) must be rotated so that a single row sonobuoy pattern oriented perpendicular to ISUBCS is rotated about the center of the initial submarine probability area to a north/south orientation east of the center of the initial submarine probability area.

GCOS - The cosine of the angle GAMMA.

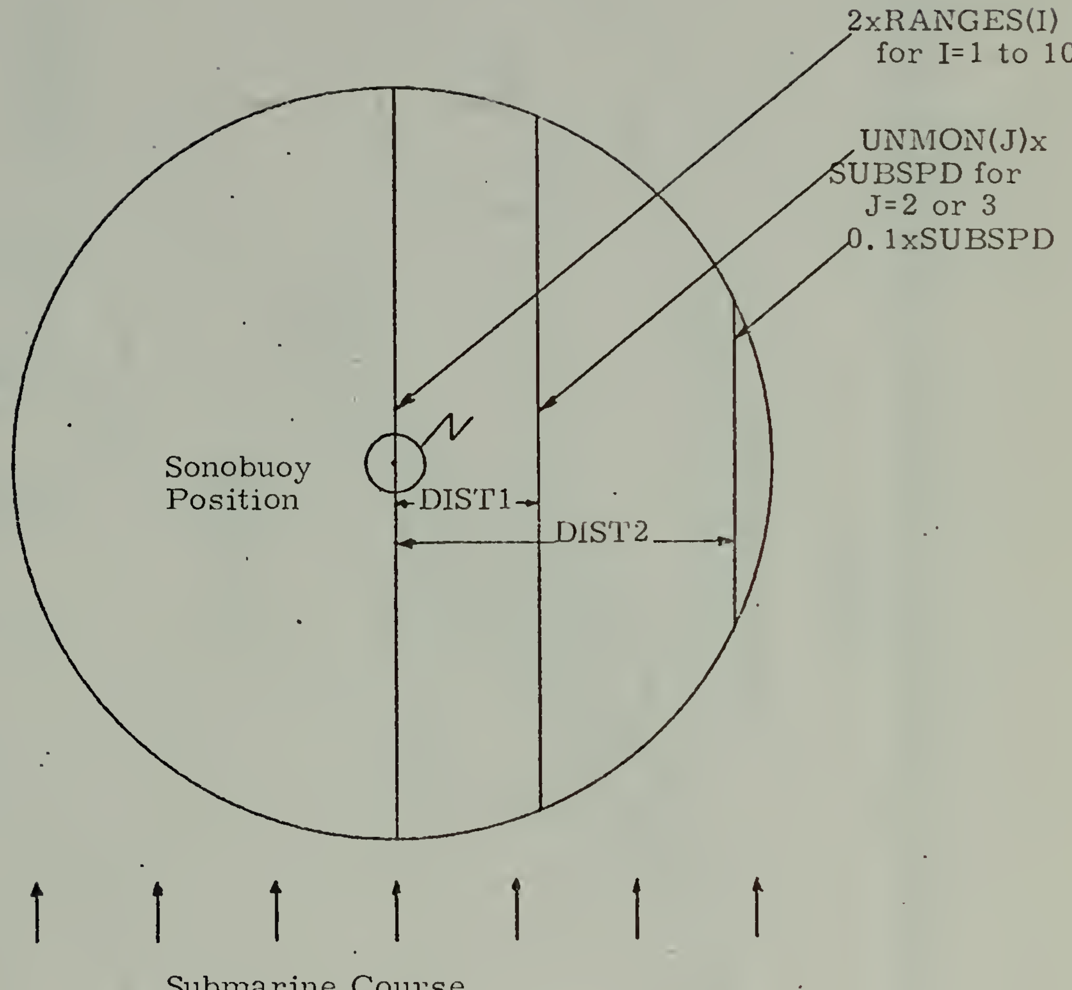

Figure 6

Sonobuoy Detection Range Penetration Areas DIST1 and DIST2

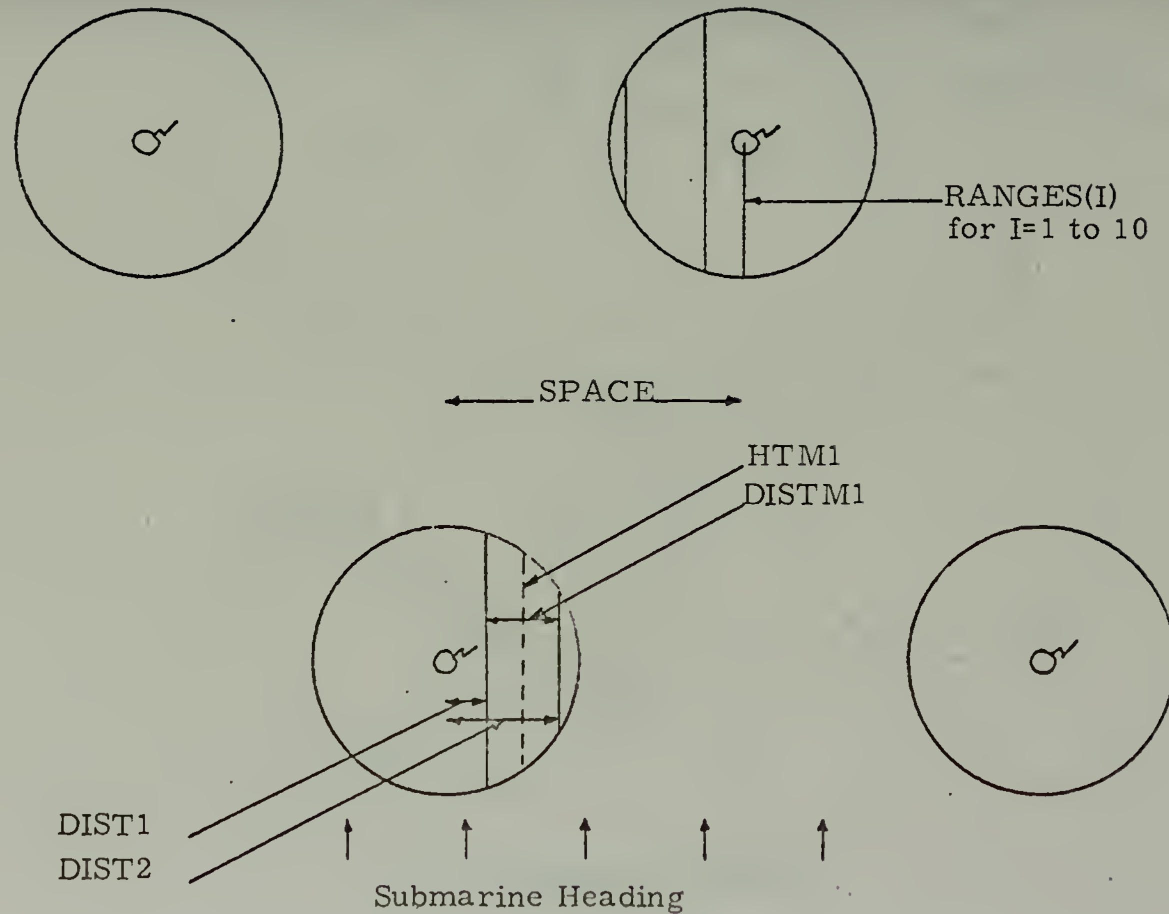

Figure 7

Two-Row Sonobuoy Pattern Detection Range Penetration Arrangement if DIST2 $\leqslant$SPACE/2.0

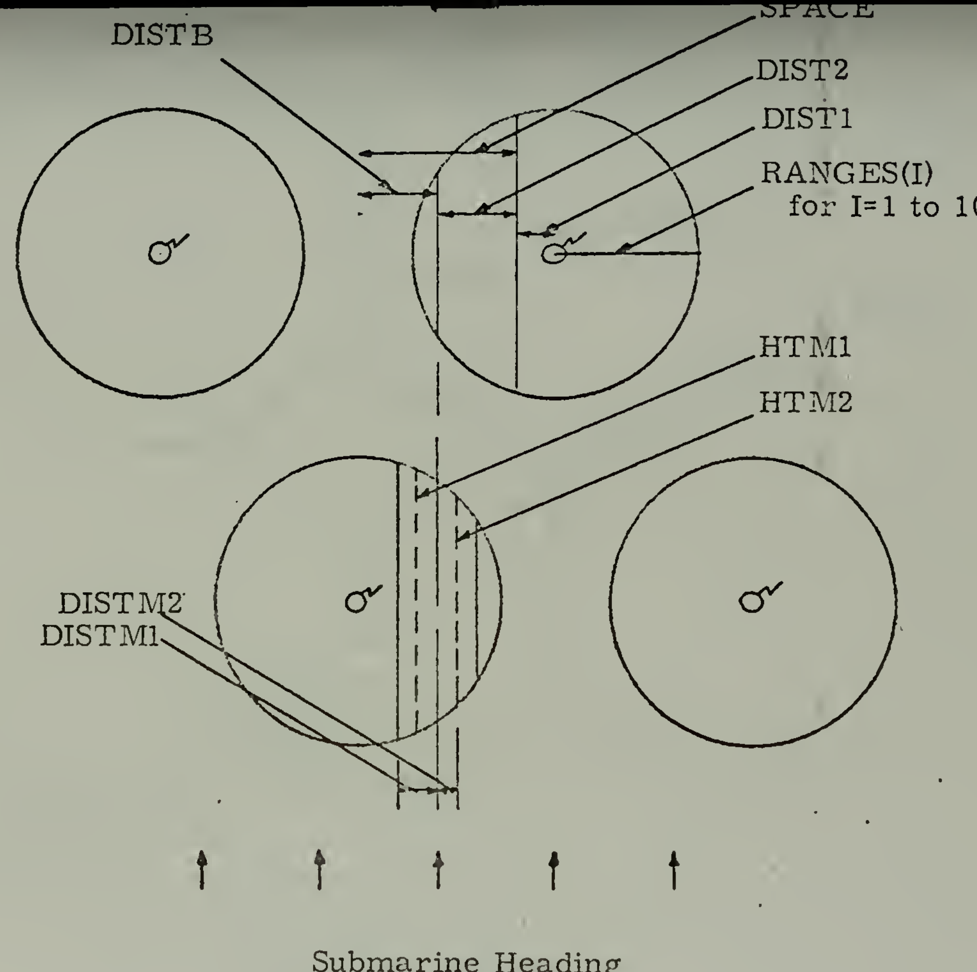

Figure 8

Two-Row Sonobuoy Pattern Detection Range Penetration Arrangement if DIST2 > SPACE/2.0 and DIST1 + DIST2 ≤ SPACE

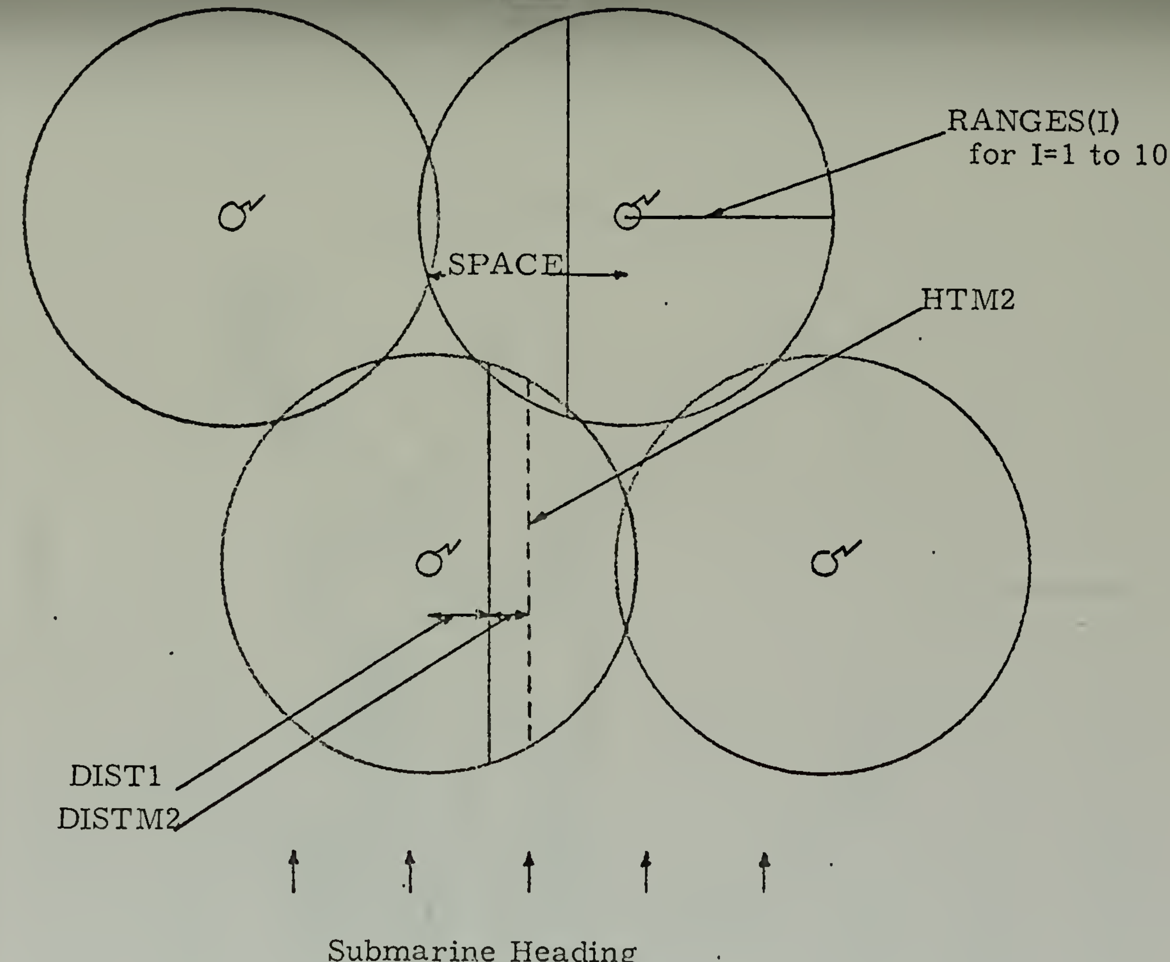

Figure 9

Two-Row Sonobuoy Pattern Detection Range Penetration Arrangement if DIST2 > SPACE/2.0 and DIST1 + DIST2 > SPACE

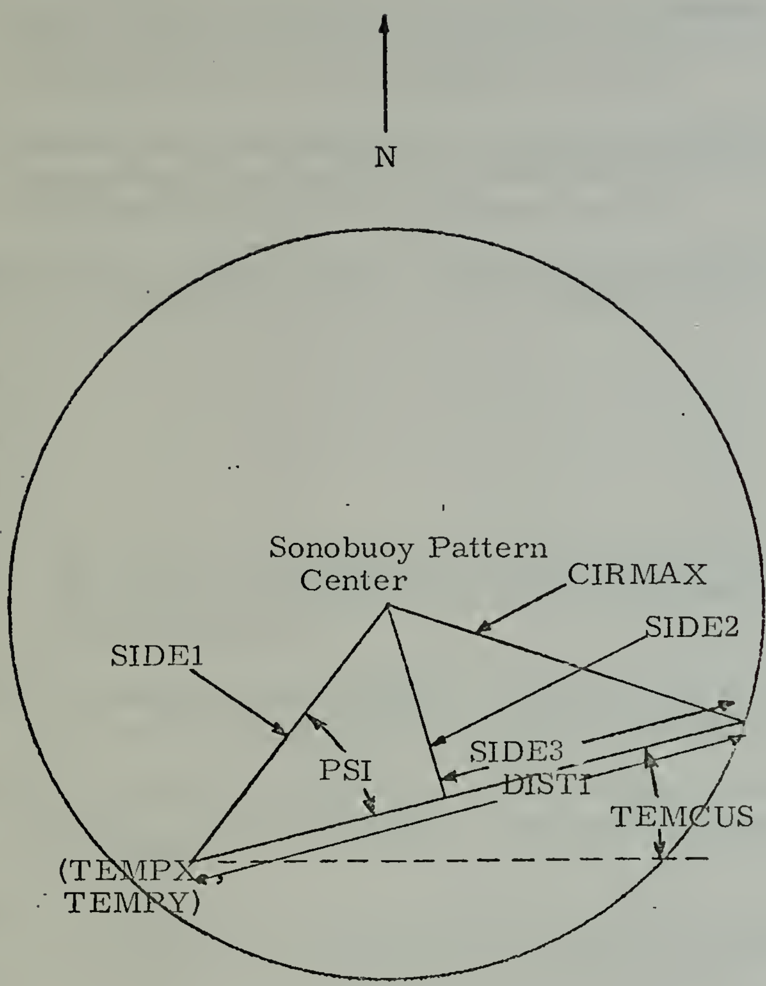

Figure 10

Toss Subroutine Arrangement at Start of Submarine Simulation Run if SIDE1 $\leqslant$ CIRMAX

GSIN - The sine of the angle GAMMA.

HT1 - With HT2, working variables used to compute HTM1 and HTM2.

HT2 - See HT1.

HTM1 - The average sonobuoy-detection-range-distance which a submarine must cross if a sonobuoy pattern zone is penetrated at a DISTM1 area. See Figures 7 and 8.

HTM2 - The average sonobuoy-detection-range-distance which a submarine must cross if a sonobuoy pattern zone is penetrated at a DISTM2 area. See Figures 8 and 9.

I1 - With LSIDE, MSIDE, I2, I3, and I4, zone pointers for construction of three monitor sequence pattern probabilities.

I2 - See I1.

I3 - See I1.

I4 - See I1.

IACALT - An integer representation of the aircraft's on-station altitude in feet above sea level. It is used for program input/output purposes.

IACSPD - An integer representation of the aircraft's on-station speed in knots. It is used for program input/output purposes.

IBMON - An integer representation of the sonobuoy monitor time per monitor cycle in minutes. It is used for program input/output purposes.

IBOYSP - An integer representation of the sonobuoy pattern spacing in nautical miles. It is used for program input/output purposes.

ICUSAC - An integer representation of the maximum angle in degrees, that the submarine is expected to deviate to either side of its projected course. It is used for program input/output purposes.

ICYCL - The number of sequences per monitor cycle computed for the optimum sonobuoy pattern.

IDATA(I) - An integer array used to store propagation-loss curve identification data.

INCR - In the TOSS subroutine, a computed number of two nautical mile increments along which the submarine has the potential to be detected by the sonobuoy pattern.

INDEX - Defines which element of the RANGES array will be used to represent the average detection range (i. e. average detection range equals RANGES(INDEX)). Preferably, RANGES(INDEX) should equal the middle-sized range, or RANGES(5). However, to prevent the average detection range from being zero, INDEX equals I where I is the first integer larger than 4 but less than 11 such that a submarine crossing through the center of RANGES(I) is detectable for at least six minutes (minimum recognizable write-out time).

INNER - For a sonobuoy pattern monitored with a three sequence monitor plan, the number of sonobuoy pattern zones that make up one monitor sequence.

INSIDE - The maximum number of sonobuoys that can be lined up in a single row with a spacing equal to IBOYSP and still fit inside RFRNG.

IOREN1 - With IOREN2 used to construct the orientation of the optimum sonobuoy pattern in degrees true.

IOREN2 - See IOREN1.

IRANGE - A random range of the simulated submarine from a sonobuoy in the RANGE subroutine. IRANGE is decreased in one-kiloyard increments until a detection is made.

ISEED - Used as a seed for the random number generating subroutine RANDOM. ISEED must be a positive integer between 1 and 2147483647 and shoud be changed periodically to ensure program randomness.

ISUBCS - An integer representation of the submarine's expected course in degrees true. It is used for program input/output purposes.

ISUBSP - An integer representation of the submarine's expected speed in knots. It is used for program input/output purposes.

LINES - The number of rows in the optimum sonobuoy pattern.

LSIDE - With MSIDE, sonobuoy pattern zone pointers used when constructing sonobuoy pattern probabilities.

MAX - With MIN the extreme end sonobuoy pattern zones during the initial construction of a three-monitor-sequence probability.

MID - The middle zone of a sonobuoy pattern during the initial construction of a three-monitor-sequence probability.

MIN - See MAX.

MISS - In the TOSS subroutine, those of the NRTOSS submarine simulations which failed to be detected by the sonobuoy pattern.

MODE - A program input parameter which designates the program mode. If MODE equals 1, IBOYSP and IBMON are computed in the GEOM subroutine. If MODE equals 2, IBOYSP and IBMON must be input to the program.

MSIDE - See LSIDE.

NPLPTS - The number of propagation-loss curve points used by the RANGE subroutine to compute the RANGES veetor array.

NRBUOY - The maximum number of sonobuoys that can be lined up in in a single row with a spaeing of IBOYSP and still fit inside ERFRNG.

NRTOSS - The number of submarine simulation runs that are made through the sonobuoy pattern area in the TOSS subroutine.

NRUNS - The number of runs used to generate the RANGES vector array in the RANGE subroutine.

NSONO - The total number of sonobuoys in the optimum sonobuoy pattern.

NSONO1 - A variable which contains the total number of sonobuoys in one-row patterns.

NSONO2 - A variable which contains the total number of sonobuoys in two-row patterns.

NSONO3 - A variable which contains the total number of sonobuoys in three-row patterns.

NSROW - A variable eontaining the number of sonobuoys in each row of the optimum sonobuoy pattern.

NVEC - Used in the call to subroutine RANDOM to designate how many uniform (O, 1) random numbers are to be generated.

OP - The sonobuoy pattern probabilities.

PART2 - The average probability that a monitor plan consisting of I sequences (where I equals two or three) will detect a submarine passing through a DISTM1 area of a sonobuoy pattern zone at SUBSPD knots, given that the detection range is a member of the RANGES vector array.

PART3 - The average probability that a monitor plan consisting of I sequences (where I equals two or three) will detect a submarine passing through a DISTM2 area of a sonobuoy pattern zone at SUBSPD knots, given that the dtection range is a member of the RANGES vector array.

PCOS - The cosine of the angle PSI.

PCX - The distance in nautical miles from the center of the initial submarine probability area to the center of the sonobuoy pattern area. It is also the horizontal component of the row of sonobuoys in the TOSS subroutine.

PD(I, J) - An array which contains the zone detection probabilities. PD(I, J) is the probability an I row zone being monitored with J sequences of BMON hours per monitor cycle will detect a submarine passing through the zones. The PD array is used with the DETECT vector array to construct pattern probabilities in the BUILD subroutine.

PHI - See Figure 5.

PI - A numerical constant initialized to 3.14159.

PLOSS(I) - A vector array which contains the propagation-loss curve, in decibels, (discretized into one kiloyard increments) out to a maximum of 250 kiloyards.

PMAX - The maximum POD found after searching through all one, two, and three row sonobuoy pattern probabilities out to a maximum pattern radius of ERFRNG.

PROB - The zone POD for a particular monitor plan, number of sonobuoy pattern rows, and sonobuoy detection range (particular value of the RANGES vector array).

PSI - See Figures 10 and 11.

PSIN - The sine of the angle PSI.

PSUM - A working variable used to sum ten values of PROB. For each summation step, the pattern rows and monitor plan are fixed, but RANGES(I) varies from I equals 1 to 10. When the summation is complete, PSUM divided by 10 is entered into the PD vector array.

PVEC(I, J) - The POD for I row sonobuoy pattern which consists of J zones.

PY(I) - A vector array which contains the vertical components of the single row of sonobuoys in the TOSS subroutine.

RANGES(I) - A vector array containing 10 equally likely expected sonobuoy detection ranges from the smallest to the largest. Theoretically, a submarine operating at a distance of RANGES(I) (where I varies from 1 to 10), from a sonobuoy will be detected (100 - Ix10) percent of the time.

RFRNG - The maximum radio-frequency range, in nautical miles (see Appendix A).

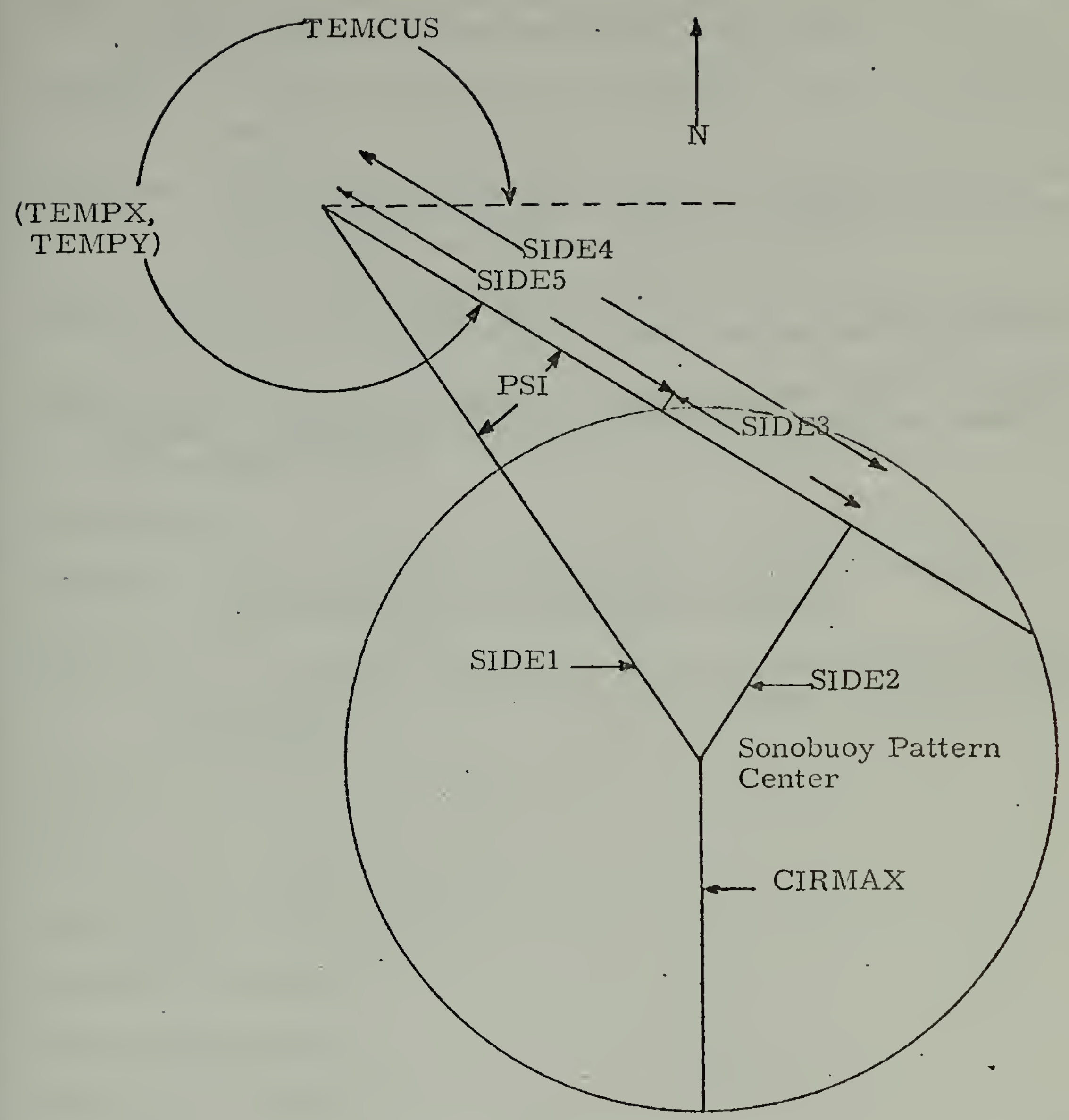

Figure 11

TOSS Subroutine Arrangement at Start of Submarine Simulation Run
if SIDE1 $>$ CIRMAX

RN(I) - A vector array used to store NVEC uniform (O, 1) random numbers generated by the RANDOM subroutine.

RNGSSQ - A working variable set to RANGES(I)^2 where I is between 1 and 10.

RNGSUM - A working variable used to sum the elements of the DETS(I) vector array, as I varies form 1 to RUNNR. In the process, the RANGES vector array is generated.

RNSUM - A working variable used to sum twelve random numbers used in the computation of the normal random variable FOMDEV.

RX - With RY defines a uniformly random position inside a rectangle similar to the initial submarine probability area but rotated to an upright position.

RY - See RX.

RUNNR - The number of random detection ranges generated in the RANGE subroutine (out of NRUNS trials).

SHIFT - The maximum radius of a one-row sonobuoy pattern which fits inside the limits of ERFRNG and has a sonobuoy spacing of IBOYSP.

SIDE1 - See Figures 10 and 11.

SIDE2 - See Figures 10 and 11.

SIDE3 - See Figures 10 and 11.

SIDE4 - See Figure 11.

SIDE5 - See Figure 11.

SIDE6 - See Figure 5.

SIGMA - A normal distribution standard deviation for the propagation-loss profile.

SPACE - In the MEET subroutine, SPACE is equal to BUOYSP when the number of sonobuoy pattern rows is one, and SPACE equals BUOYSP/2.0 when there are two or three sonobuoy pattern rows.

SQMXCR - The square of CIRMAX.

SUBCUS - The submarine's expected course in degrees true.

SUBSPD - The submarine's expected speed in knots.

TCOS - The cosine of the angle TEMCUS.

TEMCUS - The submarine course during a simulation run in the TOSS subroutine. TEMCUS varies uniformly between the limits of ICUSAC with a mean of 000 degrees.

TEMPFM - The temporary figure-of-merit computed as a random normal deviation about a mean of FOM and a standard deviation of SIGMA. TEMPFM = FOM + FOMDEV.

TEMPX - With TEMPY, defines the temporary position of the simulated submarine in the TOSS subroutine as it proceeds toward and through the sonobuoy pattern area.

TEMPY - See TEMPX.

THETA - The orientation of the initial submarine probability area. See Figure 12.

TLATE - The time that elapses between the fixing of the initial submarine probability area and the aircraft's arrival on station.

TSIN - The sine of the angle TEMCUS.

UNMON(I) - The unmonitored portion of an I sequence monitor cycle in hours.

UP - See Figure 5.

X1 - With Y1 defines one corner of the initial submarine probability area. X1 is the horizontal distance in nautical miles from that corner to a north/south line through the center of the initial submarine probability area. If the corner is to the left of the north/south line X1 has negative value. Otherwise, X1 is positive.

X2 - With Y2, defines a corner of the initial submarine probability area which is distinct from (X1, Y1), (X3, Y3), and (X4, Y4). The point (X2, Y2) is constructed in a manner similar to the construction of the point (X1, Y1).

X3 - With Y3, defines a corner of the initial submarine probability area which is distinct from (X1, Y1), (X2, Y2), and (X4, Y4). The point (X3, Y3) is constructed in a manner similar to the construction of the point (X1, Y1).

X4 - With Y4, defines a corner of the initial submarine probability area which is distinct from (X1, Y1), (X2, Y2), and (X3, Y3). The point (X4, Y4) is constructed in a manner similar to the construction of the point (X1, Y1).

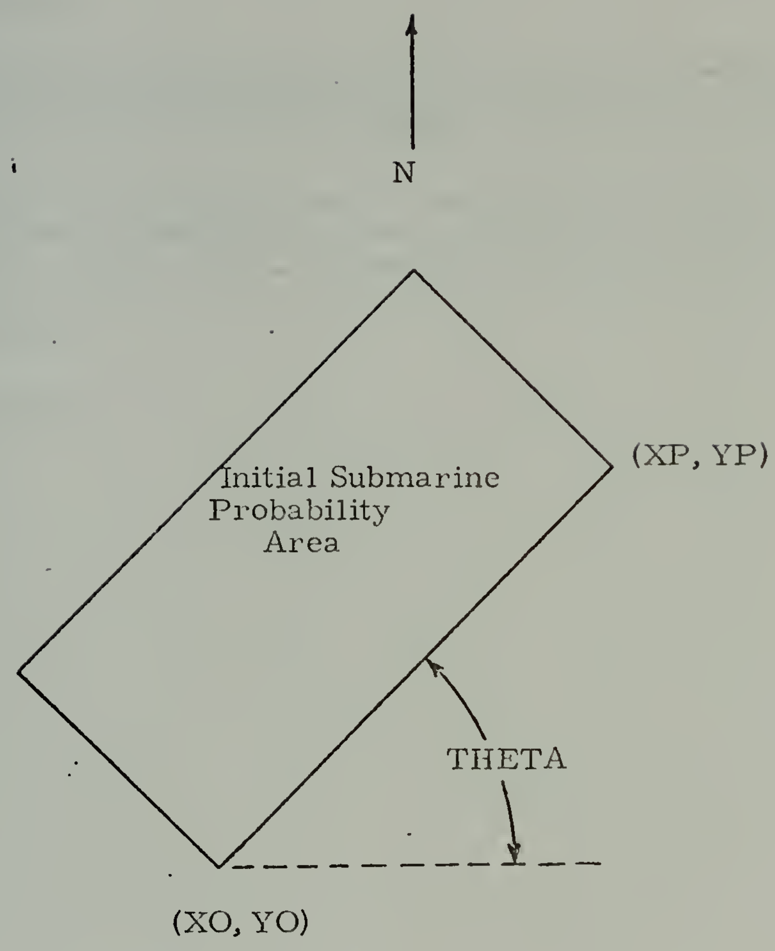

Figure 12

Initial Submarine Probability Area

Y1 - With X1 defines one corner of the initial submarine probability area. Y1 is the vertical distance in nautical miles from that corner to an east/west line through the center of the initial submarine probability area. If the corner below the east/west line Y1 has negative value. Otherwise, Y1 is positive.

Y2 - See X2.

Y3 - See X3.

Y4 - See X4.

XO - With YO, defines either the southern-most corner of the initial submarine probability area, or if there is a tie, the southwest corner of the initial submarine probability area (see Figure 12).

XP - With YP, defines either the eastern-most corner of the initial submarine probability area, or if there is a tie, the southeast corner of the initial submarine probability area (see Figure 12).

YO - See XO.

YP - See XP.

NANCEE COMPUTER PROGRAM LISTING

```
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0001
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0002
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONO,PMAXCARD0003
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,CARD0004
     43),PVEC(3,48),IDATA(40)                                           CARD0005
C                                                                       CARD0006
C     READ AND TEST PROGRAM INPUTS.                                     CARD0007
C                                                                       CARD0008
      DATA PI/3.14159/                                                  CARD0009
C                                                                       CARD0010
C     READ PROGRAM MODE.                                                CARD0011
C                                                                       CARD0012
      READ(5,800) MODE                                                  CARD0013
  800 FORMAT(3I10)                                                      CARD0014
      IF((MODE.EQ.1).OR.(MODE.EQ.2)) GO TO 10                           CARD0015
      WRITE(6,900)                                                      CARD0016
  900 FORMAT('0     EXECUTION TERMINATED.  INPUT PROGRAM MODE DOES NOT EQCARD0017
     1UAL 1 OR 2.')                                                     CARD0018
      GO TO 9000                                                        CARD0019
   10 IF(MODE.EQ.1) GO TO 20                                            CARD0020
C                                                                       CARD0021
C     IF THE PROGRAM MODE IS 2, READ THE SONOBUOY SPACING AND SONOBUOY  CARD0022
C     MONITOR TIME.                                                     CARD0023
C                                                                       CARD0024
      READ(5,800) IBOYSP,IBMON                                          CARD0025
      BUOYSP = IBOYSP                                                   CARD0026
      BMON = IBMON/60.0                                                 CARD0027
      IF((BUOYSP.GE.4).AND.(BUOYSP.LE.200)) GO TO 30                    CARD0028
      WRITE(6,910)                                                      CARD0029
  910 FORMAT('0     EXECUTION TERMINATED.  INPUT SONOBUOY SPACING OUTSIDECARD0030
     1 LIMITS 4 TO 200 NM.')                                            CARD0031
      GO TO 9000                                                        CARD0032
   30 IF((BMON.GE.0.166666).AND.(BMON.LE.1.0)) GO TO 20                 CARD0033
      WRITE(6,920)                                                      CARD0034
  920 FORMAT('0     EXECUTION TERMINATED.  INPUT SONOBUOY MONITOR TIME OUCARD0035
     1TSIDE LIMITS 10 TO 60 MINUTES.')                                  CARD0036
      GO TO 9000                                                        CARD0037
C                                                                       CARD0038
C     READ AIRCRAFT ON-STATION SPEED AND ALTITUDE.                      CARD0039
C                                                                       CARD0040
   20 READ(5,800) IACSPD,IACALT                                         CARD0041
      ACSPD = IACSPD                                                    CARD0042
      ACALT = IACALT                                                    CARD0043
      IF((ACSPD.GE.120).AND.(ACSPD.LE.350)) GO TO 40                    CARD0044
      WRITE(6,930)                                                      CARD0045
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  930 FORMAT('0    EXECUTION TERMINATED.  INPUT ACFT AIRSPEED OUTSIDE LICARD0046
     1MITS 120 TO 350 KTS.')                                            CARD0047
      GO TO 9000                                                        CARD0048
   40 IF((ACALT.GE.100).AND.(ACALT.LE.30000)) GO TO 50                  CARD0049
      WRITE(6,940)                                                      CARD0050
  940 FORMAT('0    EXECUTION TERMINATED.  INPUT ACFT ALTITUDE OUTSIDE LICARD0051
     1MITS 100 TO 30,000 FT.')                                          CARD0052
      GO TO 9000                                                        CARD0053
   50 RFRNG = 1.064*SQRT(ACALT)                                         CARD0054
      IF(RFRNG.GT.120) RFRNG = 120.0                                    CARD0055
C                                                                       CARD0056
C  READ THE SUBMARINE'S SPEED, COURSE, AND COURSE ACCURACY.             CARD0057
C                                                                       CARD0058
      READ(5,800) ISUBSP,ISUBCS,ICUSAC                                  CARD0059
      SUBSPD = ISUBSP                                                   CARD0060
      SUBCUS = ISUBCS                                                   CARD0061
      CUSACC = ICUSAC                                                   CARD0062
      IF((SUBSPD.GE.3).AND.(SUBSPD.LE.50)) GO TO 60                     CARD0063
      WRITE(6,950)                                                      CARD0064
  950 FORMAT('0    EXECUTION TERMINATED.  INPUT SUB SPEED OUTSIDE LIMITSCARD0065
     1 3 TO 50 KTS.')                                                   CARD0066
      GO TO 9000                                                        CARD0067
   60 IF((SUBCUS.GE.0).AND.(SUBCUS.LE.360)) GO TO 70                    CARD0068
      WRITE(6,960)                                                      CARD0069
  960 FORMAT('0    EXECUTION TERMINATED.  INPUT SUB COURSE OUTSIDE LIMITCARD0070
     1S 0 TO 360 DEGREES.')                                             CARD0071
      GO TO 9000                                                        CARD0072
   70 SUBCUS = SUBCUS*PI/180.0                                          CARD0073
      IF((CUSACC.GE.0).AND.(CUSACC.LE.180)) GO TO 80                    CARD0074
      WRITE(6,970)                                                      CARD0075
  970 FORMAT('0    EXECUTION TERMINATED.  INPUT COURSE ACCURACY OUTSIDE CARD0076
     1LIMITS 0 TO 180 DEGREES.')                                        CARD0077
      GO TO 9000                                                        CARD0078
   80 CUSACC = CUSACC*PI/180.0                                          CARD0079
C                                                                       CARD0080
C  READ TWO ADJACENT CORNERS OF THE INITIAL SUBMARINE PROGABILITY AREA.CARD0081
C                                                                       CARD0082
      READ(5,810) X1,Y1,X2,Y2                                           CARD0083
  810 FORMAT(4F10.1)                                                    CARD0084
      IF(((X1 - X2)**2 + (Y1 - Y2)**2).GE.1000000) GO TO 90             CARD0085
      IF(((X1 + X2)**2 + (Y1 + Y2)**2).LT.1000000) GO TO 100            CARD0086
   90 WRITE(6,980)                                                      CARD0087
  980 FORMAT('0    EXECUTION TERMINATED.  INPUT INITIAL PROBABILITY AREACARD0088
     1 HAS ONE SIDE LONGER THAN 1000 NM.')                              CARD0089
      GO TO 9000                                                        CARD0090
C                                                                       CARD0091
C  READ TIME-LATE.                                                      CARD0092
C                                                                       CARD0093
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  100 READ(5,810) TLATE                                                      CARD0094
      IF((TLATE.GE.0).AND.(TLATE.LE.48)) GO TO 110                           CARD0095
      WRITE(6,990)                                                           CARD0096
  990 FORMAT('0    EXECUTION TERMINATED.  INPUT TIME LATE OUTSIDE LIMITSCARD0097
     1 0 TO 48 HOURS.')                                                      CARD0098
      GO TO 9000                                                             CARD0099
C                                                                            CARD0100
C   READ THE TARGET'S FIGURE-OF-MERIT AND THE NUMBER OF PROPAGATION-         CARD0101
C   LOSS CURVE POINTS WHICH ARE TO BE USED.                                  CARD0102
C                                                                            CARD0103
  110 READ(5,820) FOM,NPLPTS                                                 CARD0104
  820 FORMAT(F10.1,I10)                                                      CARD0105
      IF((FOM.GE.0).AND.(FOM.LE.220)) GO TO 120                              CARD0106
      WRITE(6,1000)                                                          CARD0107
 1000 FORMAT('0    EXECUTION TERMINATED.  INPUT FOM OUTSIDE LIMITS 0 TO CARD0108
     1220 DB.')                                                              CARD0109
      GO TO 9000                                                             CARD0110
  120 IF((NPLPTS.GE.0).AND.(NPLPTS.LE.250)) GO TO 130                        CARD0111
      WRITE(6,1010)                                                          CARD0112
 1010 FORMAT('0    EXECUTION TERMINATED.  INPUT NUMBER OF PROPLOSS PTS ICARD0113
     1S OUTSIDE LIMITS 0 TO 250.')                                           CARD0114
      GO TO 9000                                                             CARD0115
C                                                                            CARD0116
C   READ THE PROPAGATION-LOSS CURVE HEADING DATA.                            CARD0117
C                                                                            CARD0118
  130 READ(5,830) (IDATA(I),I=1,40)                                          CARD0119
  830 FORMAT(20A4)                                                           CARD0120
C                                                                            CARD0121
C   READ THE PROPAGATION-LOSS CURVE IN 1 KYD INCREMENTS.                     CARD0122
C                                                                            CARD0123
      READ(5,840) (PLOSS(I),I=1,NPLPTS)                                      CARD0124
  840 FORMAT(10X,10F7.1)                                                     CARD0125
      CALL RANGE                                                             CARD0126
      IF(INDEX.LT.11) GO TO 140                                              CARD0127
      WRITE(6,1020)                                                          CARD0128
 1020 FORMAT('0    EXECUTION TERMINATED.  INPUT FOM IS TOO LOW TO PRODUCCARD0129
     1E DETECTIONS AGAINST THE INPUT PROPLOSS CURVE.')                       CARD0130
      GO TO 9000                                                             CARD0131
  140 CALL GEOM                                                              CARD0132
      CALL TOSS                                                              CARD0133
      CALL MEET                                                              CARD0134
      CALL BUILD                                                             CARD0135
      CALL MAKEUP                                                            CARD0136
      CALL OUTPUT                                                            CARD0137
 9000 STOP                                                                   CARD0138
      END                                                                    CARD0139
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      SUBROUTINE RANGE                                                  CARD0140
      DIMENSION DETS(251),RN(6500)                                      CARD0141
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0142
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0143
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONO,PMAXCARD0144
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,CARD0145
     43),PVEC(3,48),IDATA(40)                                           CARD0146
      DATA NRUNS,SIGMA,ISEED/500,5.0,3218047/                           CARD0147
C                                                                       CARD0148
C    GENERATE RUNNR RANDOM DETECTION RANGES AND CHOOSE 10 AS EQUALLY    CARD0149
C    LIKELY REPRESENTATIVES OF THE OTHERS.                              CARD0150
C                                                                       CARD0151
      DO 10 I=1,NPLPTS                                                  CARD0152
      DETS(I) = 0.0                                                     CARD0153
   10 CONTINUE                                                          CARD0154
      RUNNR = 0.0                                                       CARD0155
      NVEC = 13*NRUNS                                                   CARD0156
      M = 12*NRUNS                                                      CARD0157
      CALL RANDOM(ISEED,RN,NVEC)                                        CARD0158
      DO 20 I=1,NRUNS                                                   CARD0159
      RNSUM = 0.0                                                       CARD0160
      K = (I - 1)*12                                                    CARD0161
      DO 30 J=1,12                                                      CARD0162
      L = K + J                                                         CARD0163
      RNSUM = RNSUM + RN(L)                                             CARD0164
   30 CONTINUE                                                          CARD0165
      FOMDEV = SIGMA*(RNSUM - 6.0)                                      CARD0166
      TEMPFM = FOM + FOMDEV                                             CARD0167
      IRANGE = NPLPTS*RN(M + I) + 1                                     CARD0168
      IF(TEMPFM.GE.PLOSS(IRANGE)) GO TO 20                              CARD0169
      GO TO 50                                                          CARD0170
   40 IF(TEMPFM.GE.PLOSS(IRANGE)) GO TO 60                              CARD0171
   50 IRANGE = IRANGE - 1                                               CARD0172
      IF(IRANGE.EQ.0) GO TO 60                                          CARD0173
      GO TO 40                                                          CARD0174
   60 DETS(IRANGE + 1) = DETS(IRANGE + 1) + 1.0                         CARD0175
      RUNNR = RUNNR + 1.0                                               CARD0176
   20 CONTINUE                                                          CARD0177
      RNGSUM = 0.0                                                      CARD0178
      J = 0                                                             CARD0179
      DO 70 I=1,10                                                      CARD0180
      GO TO 90                                                          CARD0181
   80 J = J + 1                                                         CARD0182
      RNGSUM = RNGSUM + DETS(J)                                         CARD0183
   90 IF(RNGSUM.LT.(RUNNR*I)/10) GO TO 80                               CARD0184
      RANGES(I) = 0.493827*(J - 1)                                      CARD0185
   70 CONTINUE                                                          CARD0186
      INDEX = 4                                                         CARD0187
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100 INDEX = INDEX + 1                                                   CARD0188
    IF(INDEX.EQ.11) GO TO 110                                           CARD0189
    IF(RANGES(INDEX).LE.(0.05*SUBSPD)) GO TO 100                        CARD0190
110 RETURN                                                              CARD0191
    END                                                                 CARD0192
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      SUBROUTINE GEOM                                                   CARD0193
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0194
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0195
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONO,PMAXCARD0196
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,CARD0197
     43),PVEC(3,48),IDATA(40)                                           CARD0198
C                                                                       CARD0199
C    PREPARE THE INITIAL SUBMARINE PROBABILITY AREA AND SONOBUOY PATTERN CARD0200
C    AREA FOR SIMULATION IN THE TOSS SUBROUTINE.                        CARD0201
C                                                                       CARD0202
      AX1 = ABS(X1)                                                     CARD0203
      AX2 = ABS(X2)                                                     CARD0204
      AY1 = ABS(Y1)                                                     CARD0205
      AY2 = ABS(Y2)                                                     CARD0206
      IF(AY2 - AY1) 10,20,30                                            CARD0207
   10 IF(Y1.LT.0) GO TO 40                                              CARD0208
      XO = -X1                                                          CARD0209
      YO = -Y1                                                          CARD0210
      GO TO 50                                                          CARD0211
   40 XO = X1                                                           CARD0212
      YO = Y1                                                           CARD0213
   50 IF(X2.GT.0) GO TO 60                                              CARD0214
      XP = -X2                                                          CARD0215
      YP = -Y2                                                          CARD0216
      GO TO 100                                                         CARD0217
   60 XP = X2                                                           CARD0218
      YP = Y2                                                           CARD0219
      GO TO 100                                                         CARD0220
   20 XO = -AX1                                                         CARD0221
      YO = -AY1                                                         CARD0222
      XP = AX1                                                          CARD0223
      YP = -AY1                                                         CARD0224
      GO TO 100                                                         CARD0225
   30 IF(Y2.LT.0) GO TO 70                                              CARD0226
      XO = -X2                                                          CARD0227
      YO = -Y2                                                          CARD0228
      GO TO 80                                                          CARD0229
   70 XO = X2                                                           CARD0230
      YO = Y2                                                           CARD0231
   80 IF(X1.GT.0) GO TO 90                                              CARD0232
      XP = -X1                                                          CARD0233
      YP = -Y1                                                          CARD0234
      GO TO 100                                                         CARD0235
   90 XP = X1                                                           CARD0236
      YP = Y1                                                           CARD0237
  100 THETA = ATAN((YP - YO)/(XP - XO))                                 CARD0238
      DX = SQRT((XP - XO)**2 + (YP - YO)**2)/2.0                        CARD0239
      DY = SQRT((XP + XO)**2 + (YP + YO)**2)/2.0                        CARD0240
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      IF(MODE.EQ.2) GO TO 110                                          CARD0241
      IBOYSP = 1.41421*RANGES(INDEX)                                   CARD0242
      IF(IBOYSP.LT.4) IBOYSP = 4                                       CARD0243
      BUOYSP = IBOYSP                                                  CARD0244
      BMON = (BUOYSP/SUBSPD - 0.333333)/2.0                            CARD0245
      IF(BMON.GT.1.0) BMON = 1.0                                       CARD0246
      IF(BMON.LT.0.166666) BMON = 0.166666                             CARD0247
      IBMON = 60*BMON + 1                                              CARD0248
  110 UNMON(2) = BMON                                                  CARD0249
      CYCLE(2) = 2.0*BMON                                              CARD0250
      UNMON(3) = CYCLE(2)                                              CARD0251
      CYCLE(3) = 3.0*BMON                                              CARD0252
      ERFRNG = RFRNG + 0.25*(BMON*ACSPD)                               CARD0253
      NRBUOY = ((2*ERFRNG)/BUOYSP) + 1                                 CARD0254
      INSIDE = ((2*RFRNG)/BUOYSP) + 1                                  CARD0255
      PCX = XP + SUBSPD*(TLATE + 1.0 + (6*ERFRNG)/ACSPD)               CARD0256
      BSUM = 0.0                                                       CARD0257
      SHIFT = BUOYSP*(NRBUOY - 1)/2.0                                  CARD0258
      DO 120 I=1,NRBUOY                                                CARD0259
      PY(I) = BSUM - SHIFT                                             CARD0260
      BSUM = BSUM + BUOYSP                                             CARD0261
  120 CONTINUE                                                         CARD0262
      RETURN                                                           CARD0263
      END                                                              CARD0264
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      SUBROUTINE TOSS                                                   CARD0265
      DIMENSION RN(1500)                                                CARD0266
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0267
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0268
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONO,PMAXCARD0269
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMCN(3),CYCLE(3),PD(3,CARD0270
     43),PVEC(3,48),IDATA(40)                                           CARD0271
      DATA ISEED/8241905/                                               CARD0272
C                                                                       CARD0273
C    MAKE NRTOSS RANDOM SIMULATIONS THROUGH THE SONOBUOY PATTERN AREA.  CARD0274
C    HENCE, DETERMINE THE PROBABILITIES THAT A SUBMARINE WILL PASS      CARD0275
C    THROUGH VARIOUS ZONES OF THE SONOBUOY PATTERN.                     CARD0276
C                                                                       CARD0277
      NRTOSS = 500                                                      CARD0278
      RNGSSQ = RANGES(INDEX)**2                                         CARD0279
      GAMMA = (1.5708 - SUBCUS) - THETA                                 CARD0280
      GSIN = SIN(GAMMA)                                                 CARD0281
      GCOS = COS(GAMMA)                                                 CARD0282
      CIRMAX = SHIFT + RANGES(INDEX)                                    CARD0283
      SQMXCR = CIRMAX**2                                                CARD0284
      MISS = 0                                                          CARD0285
      DO 10 I=1,NRBUOY                                                  CARD0286
      DETECT(I) = 0                                                     CARD0287
   10 CONTINUE                                                          CARD0288
      NVEC = 3*NRTOSS                                                   CARD0289
      CALL RANDOM(ISEED,RN,NVEC)                                        CARD0290
      DO 20 I=1,NRTOSS                                                  CARD0291
      RX = DX*(2.0*RN(I) - 1)                                           CARD0292
      RY = DY*(2.0*RN(NRTOSS + I) - 1)                                  CARD0293
      TEMPX = RX*GCOS + RY*GSIN                                         CARD0294
      TEMPY = RY*GCOS - RX*GSIN                                         CARD0295
      TEMCUS = CUSACC*(2.0*RN(2*NRTOSS + I) -1)                         CARD0296
      TSIN = SIN(TEMCUS)                                                CARD0297
      TCOS = COS(TEMCUS)                                                CARD0298
      PHI = ATAN2(-TEMPY,(PCX - TEMPX))                                 CARD0299
      PSI = PHI - TEMCUS                                                CARD0300
      PCOS = COS(PSI)                                                   CARD0301
      IF(PSI.LT.0) PSI = -PSI                                           CARD0302
      PSIN = SIN(PSI)                                                   CARD0303
      SIDE1 = SQRT((PCX - TEMPX)**2 + TEMPY**2)                         CARD0304
      IF(CIRMAX.LT.SIDE1) GO TO 30                                      CARD0305
      SIDE2 = SIDE1*PSIN                                                CARD0306
      SIDE3 = SQRT(SQMXCR - SIDE2**2)                                   CARD0307
      DISTI = SIDE1*PCOS + SIDE3                                        CARD0308
      INCP = DISTI/2.0 + 1.0                                            CARD0309
      GO TO 40                                                          CARD0310
   30 SIDE6 = SQRT(SIDE1**2 - SQMXCR)                                   CARD0311
      ALFA = ATAN(CIRMAX/SIDE6)                                         CARD0312
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      UP = PHI + ALFA                                                   CARD0313
      DCWN = PHI - ALFA                                                 CARD0314
      IF((TEMCUS.GT.UP).OR.(TEMCUS.LT.DCWN)) GO TC 70                   CARD0315
      SIDE2 = SIDE1*PSIN                                                CARD0316
      SIDE3 = SQRT(SQMXCR - SIDE2**2)                                   CARD0317
      INCR = SIDE3 + 1.0                                                CARD0318
      SIDE4 = SIDE1*PCOS                                                CARD0319
      SIDE5 = SIDE4 - SIDE3                                             CARD0320
      TEMPX = TEMPX + SIDE5*TCOS                                        CARD0321
      TEMPY = TEMPY + SIDE5*TSIN                                        CARD0322
   40 DC 50 J=1,INCR                                                    CARD0323
      DC 60 K=1,NRBUOY                                                  CARD0324
      BUOYD = (TEMPX - PCX)**2 + (TEMPY - PY(K))**2                     CARD0325
      IF(BUCYD.GT.RNGSSQ) GO TO 60                                      CARD0326
      DETECT(K) = DETECT(K) + 1                                         CARD0327
      GO TO 20                                                          CARD0328
   60 CCNTINUE                                                          CARD0329
      TEMPX = TEMPX + 2.0*TCOS                                          CARD0330
      TEMPY = TEMPY + 2.0*TSIN                                          CARD0331
   50 CCNTINUE                                                          CARD0332
   70 MISS = MISS + 1                                                   CARD0333
   20 CCNTINUE                                                          CARD0334
      DC 90 I=1,NRBUOY                                                  CARD0335
      DETECT(I) = DETECT(I)/NRTOSS                                      CARD0336
   90 CCNTINUE                                                          CARD0337
      RETURN                                                            CARD0338
      END                                                               CARD0339
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      SUBROUTINE MEET                                                   CARD0340
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0341
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0342
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONO,PMAXCARD0343
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,CARD0344
     43),PVEC(3,48),IDATA(40)                                           CARD0345
C                                                                       CARD0346
C    FOR EACH COMBINATION OF SONOBUOY PATTERN ROWS AND PATTERN MONITOR  CARD0347
C    SEQUENCES BETWEEN 1 AND 3, THE PROBABILITY THAT A SUBMARINE WILL   CARD0348
C    BE DETECTED IN A ZONE UNDER THOSE CONDITIONS IS CALCULATED.        CARD0349
C    THESE ARE THE "MEETING" PROBABILITIES.                             CARD0350
C                                                                       CARD0351
      SPACE = BUOYSP                                                    CARD0352
      FILL1 = 0.05*SUBSPD                                               CARD0353
      DO 10 I=1,3                                                       CARD0354
      IF(I.EQ.2) SPACE = SPACE/2.0                                      CARD0355
      FILL2 = SPACE/2.0                                                 CARD0356
      DO 20 J=1,3                                                       CARD0357
      PSUM = 0.0                                                        CARD0358
      DO 30 K=1,10                                                      CARD0359
      RNGSSQ = RANGES(K)**2                                             CARD0360
      IF(FILL1.LT.RANGES(K)) GO TO 40                                   CARD0361
      PROB = 0.0                                                        CARD0362
      GO TO 130                                                         CARD0363
   40 DIST2 = SQRT(RNGSSQ - FILL1**2)                                   CARD0364
      IF(J.GT.1) GO TO 50                                               CARD0365
      IF(DIST2.LT.FILL2) GO TO 60                                       CARD0366
      PROB = 1.0                                                        CARD0367
      GO TO 130                                                         CARD0368
   60 PROB = DIST2/FILL2                                                CARD0369
      GO TO 130                                                         CARD0370
   50 FILL3 = UNMON(J)*(SUBSPD/2.0)                                     CARD0371
      IF(FILL3.LT.RANGES(K)) GO TO 70                                   CARD0372
      DIST1 = 0.0                                                       CARD0373
      GO TO 80                                                          CARD0374
   70 DIST1 = SQRT(RNGSSQ - FILL3**2)                                   CARD0375
   80 IF(DIST1.LT.FILL2) GO TO 90                                       CARD0376
      PROB = 1.0                                                        CARD0377
      GO TO 130                                                         CARD0378
   90 IF(DIST2.GE.FILL2) GO TO 100                                      CARD0379
      DISTM1 = DIST2 - DIST1                                            CARD0380
      HT1 = FILL1                                                       CARD0381
      HT2 = FILL3                                                       CARD0382
      HTM1 = HT1 + HT2                                                  CARD0383
      DISTM2 = 0.0                                                      CARD0384
      HTM2 = 0.0                                                        CARD0385
      GO TO 120                                                         CARD0386
  100 IF((DIST1 + DIST2).LT.SPACE) GO TO 110                            CARD0387
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      DISTM1 = 0.0                                                      CARD0388
      HTM1 = 0.0                                                        CARD0389
      DISTM2 = FILL2 - DIST1                                            CARD0390
      HT1 = FILL1                                                       CARD0391
      HT2 = SQRT(RNGSSQ - FILL2**2)                                     CARD0392
      HTM2 = HT1 + HT2                                                  CARD0393
      GO TO 120                                                         CARD0394
  110 DISTB = SPACE - DIST2                                             CARD0395
      DISTM1 = DISTB - DIST1                                            CARD0396
      HT1 = FILL1                                                       CARD0397
      HT2 = SQRT(RNGSSQ - DISTB**2)                                     CARD0398
      HTM1 = HT1 + HT2                                                  CARD0399
      DISTM2 = (DIST2 - DISTB)/2.0                                      CARD0400
      HT1 = FILL3                                                       CARD0401
      HTM2 = HT1 + HT2                                                  CARD0402
  120 PART2 = 1.0 - ((0.1 + UNMON(J))**2 + (CYCLE(J) - HTM1/SUBSPD)**2)/CARD0403
     1(2.0*CYCLE(J)**2)                                                 CARD0404
      PART3 = 1.0 - ((0.1 + UNMON(J))**2 + (CYCLE(J) - HTM2/SUBSPD)**2)/CARD0405
     1(2.0*CYCLE(J)**2)                                                 CARD0406
      IF(I.NE.3) PROB = (DIST1 + DISTM1*PART2 + DISTM2*(PART3*(2 - PART3CARD0407
     1)))/FILL2                                                         CARD0408
      IF(I.EQ.3) PROB = (DIST1 + DISTM1*(PART2*(3 - PART2))/2.0 + DISTM2CARD0409
     1*(PART3*(PART3**2 - 3*PART3 + 3)))/FILL2                          CARD0410
  130 PSUM = PSUM + PROB                                                CARD0411
   30 CONTINUE                                                          CARD0412
      PD(I,J) = PSUM/10.0                                               CARD0413
   20 CONTINUE                                                          CARD0414
   10 CONTINUE                                                          CARD0415
      RETURN                                                            CARD0416
      END                                                               CARD0417
```

```
      SUBROUTINE BUILD                                                  CARD0418
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0419
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0420
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONO,PMAXCARD0421
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,CARD0422
     43),PVEC(3,48),IDATA(40)                                           CARD0423
C                                                                       CARD0424
C    THE ZONE PASSAGE PROBABILITEES (SUBROUTINE TOSS) ALONG WITH THE    CARD0425
C    ZONE MEETING PROBABILITIES (SUBROUTINE MEET) ARE PIECED TOGETHER TO CARD0426
C    FORM PATTERN PROBABILITIES.                                        CARD0427
C                                                                       CARD0428
      LOGICAL FLAG                                                      CARD0429
      LINES = 1                                                         CARD0430
      NSONO = 1                                                         CARD0431
      PMAX = 0.0                                                        CARD0432
      DO 10 I=1,3                                                       CARD0433
      LSIDE = NRBUOY/2                                                  CARD0434
      IF(LSIDE*2.NE.NRBUOY) LSIDE = LSIDE + 1                           CARD0435
      MSIDE = LSIDE + 1                                                 CARD0436
      FLAG = .FALSE.                                                    CARD0437
      OP = 0.0                                                          CARD0438
      ICYCL = 1                                                         CARD0439
      DO 20 J=1,NRBUOY                                                  CARD0440
      IF(I*J.GT.48) GO TO 10                                            CARD0441
      IF((J.GT.(INSIDE + 1)).OR.(I*J.GT.32)) GO TO 30                   CARD0442
      IF(I*J.GT.16) ICYCL = 2                                           CARD0443
      K = ICYCL                                                         CARD0444
      IF((J/2)*2.EQ.J) GO TO 40                                         CARD0445
      OP = OP + PD(I,K)*DETECT(LSIDE)                                   CARD0446
      IF(K.EQ.1) GO TO 50                                               CARD0447
      OP = OP - PD(I,K - 1)*DETECT(LSIDE + 16/I) + PD(I,K)*DETECT(LSIDE CARD0448
     1+ 16/I)                                                           CARD0449
   50 LSIDE = LSIDE - 1                                                 CARD0450
      GO TO 60                                                          CARD0451
   40 OP = OP + PD(I,K)*DETECT(MSIDE)                                   CARD0452
      IF(K.EQ.1) GO TO 70                                               CARD0453
      OP = OP - PD(I,K - 1)*DETECT(MSIDE - 16/I) + PD(I,K)*DETECT(MSIDE CARD0454
     1- 16/I)                                                           CARD0455
   70 MSIDE = MSIDE + 1                                                 CARD0456
      GO TO 60                                                          CARD0457
   30 IF(FLAG) GO TO 80                                                 CARD0458
      FLAG = .TRUE.                                                     CARD0459
      ICYCL = 3                                                         CARD0460
      INNER = (16/I) - 1                                                CARD0461
      IF(INSIDE.LT.16/I) INNER = INSIDE - 1                             CARD0462
      IF((J/2)*2.EQ.J) GO TO 90                                         CARD0463
      MIN = LSIDE                                                       CARD0464
      MAX = MSIDE - 1                                                   CARD0465
```

```
      LSIDE = LSIDE - 1
      GO TO 100
   90 MIN = LSIDE + 1
      MAX = MSIDE
      MSIDE = MSIDE + 1
  100 MID = MIN + (MAX - MIN)/2
      I1 = MID - INNER/2
      I2 = MIN + INNER
      I3 = MAX - INNER
      I4 = I1 + INNER
      OP = 0.0
      J1 = I1 - 1
      DO 110 N=MIN,J1
      OP = OP + PD(I,3)*DETECT(N)
  110 CONTINUE
      IF(I3 - (I2 + 1)) 120,130,140
  120 J1 = I3 - 1
      DO 150 N=I1,J1
      OP = OP + PD(I,2)*DETECT(N)
  150 CONTINUE
      DO 160 N=I3,I2
      OP = OP + PD(I,1)*DETECT(N)
  160 CONTINUE
      J1 = I2 + 1
      DO 170 N=J1,I4
      OP = OP + PD(I,2)*DETECT(N)
  170 CONTINUE
      GO TO 180
  130 DO 190 N=I1,I4
      OP = OP + PD(I,2)*DETECT(N)
  190 CONTINUE
      GO TO 180
  140 DO 200 N=I1,I2
      OP = OP + PD(I,2)*DETECT(N)
  200 CONTINUE
      J1 = I2 + 1
      J2 = I3 - 1
      DO 210 N=J1,J2
      OP = OP + PD(I,3)*DETECT(N)
  210 CONTINUE
      DO 220 N=I3,I4
      OP = OP + PD(I,2)*DETECT(N)
  220 CONTINUE
  180 J1 = I4 + 1
      DO 230 N=J1,MAX
      OP = OP + PD(I,3)*DETECT(N)
  230 CONTINUE
      GO TO 60
```

```
 80 K = 1                                                                CARD0514
    IF(I3.GE.I2) K = 2                                                   CARD0515
    IF((J/2)*2.EQ.J) GO TO 240                                           CARD0516
    OP = OP + PD(I,3)*DETECT(LSIDE) - PD(I,K)*DETECT(I2) + PD(I,K + 1)CARD0517
   1*DETECT(I2)                                                          CARD0518
    LSIDE = LSIDE - 1                                                    CARD0519
    I2 = I2 - 1                                                          CARD0520
    GO TO 60                                                             CARD0521
240 OP = OP + PD(I,3)*DETECT(MSIDE) - PD(I,K)*DETECT(I3) + PD(I,K + 1)CARD0522
   1*DETECT(I3)                                                          CARD0523
    MSIDE = MSIDE + 1                                                    CARD0524
    I3 = I3 + 1                                                          CARD0525
 60 IF((OP - PMAX).LT.0.00005) GO TO 250                                 CARD0526
    PMAX = OP                                                            CARD0527
    LINES = I                                                            CARD0528
    NSONO = J*I                                                          CARD0529
250 PVEC(I,J) = OP                                                       CARD0530
 20 CONTINUE                                                             CARD0531
 10 CONTINUE                                                             CARD0532
    RETURN                                                               CARD0533
    END                                                                  CARD0534
```

```
      SUBROUTINE MAKEUP                                                 CARD0535
      COMMON MODE,BMON,IBMON,ACSPC,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,ISCARD0536
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,CARD0537
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSCNO,PMAXCARD0538
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,CARD0539
     43),PVEC(3,48),IDATA(40)                                           CARD0540
C                                                                       CARD0541
C   DATA SIGNIFICANT WHEN COMPUTING THE PROGRAM RESULTS IS OUTPUT.      CARD0542
C                                                                       CARD0543
      WRITE(6,900)                                                      CARD0544
  900 FORMAT('1',59X,'NANCEE MAKEUP',/)                                 CARD0545
      WRITE(6,910)                                                      CARD0546
  910 FORMAT('0 RANGES ARRAY',/)                                        CARD0547
      WRITE(6,920) (RANGES(I),I=1,10)                                   CARD0548
  920 FORMAT(' ',F10.1)                                                 CARD0549
      WRITE(6,930)                                                      CARD0550
  930 FORMAT(' ',/////,'  DETECT ARRAY',/)                              CARD0551
      WRITE(6,940) (DETECT(I),I=1,NRBUOY)                               CARD0552
  940 FORMAT(' ',10F10.5)                                               CARD0553
      WRITE(6,950)                                                      CARD0554
  950 FORMAT(' ',/////,'  PD ARRAY',5X,'ROWS',5X,'SEQUENCES',/)         CARD0555
      DO 10 I=1,3                                                       CARD0556
      WRITE(6,960) ((PD(I,J),I,J),J=1,3)                                CARD0557
  960 FORMAT(' ',F10.4,4X,I2,9X,I2)                                     CARD0558
   10 CONTINUE                                                          CARD0559
      RETURN                                                            CARD0560
      END                                                               CARD0561
```

```
      SUBROUTINE OUTPUT
      COMMON MODE,BMON,IBMON,ACSPD,SUBSPD,SUBCUS,CUSACC,IACSPD,IACALT,IS
     1UBSP,ISUBCS,ICUSAC,TLATE,FOM,BUOYSP,IBOYSP,NPLPTS,INSIDE,INDEX,X1,
     2Y1,X2,Y2,DX,DY,RFRNG,NRBUOY,SHIFT,THETA,PCX,ICYCL,LINES,NSONC,PMAX
     3,PLOSS(250),RANGES(10),PY(150),DETECT(150),UNMON(3),CYCLE(3),PD(3,
     43),PVEC(3,48),IDATA(40)
C
C   THE PROGRAM RESULTS ARE OUTPUT.
C
      X3 = -X1
      Y3 = -Y1
      X4 = -X2
      Y4 = -Y2
      WRITE(6,900)
  900 FORMAT('1',59X,'NANCEE OUTPUT',/)
      WRITE(6,910)
  910 FORMAT('0ROWS SONOBUOYS      PD',20X,'ROWS SONOBUOYS      PD',20X,'R
     1OWS SONOBUOYS      PD')
      K1 = NRBUOY
      IF(NRBUOY.GT.16) K1 = 16
      K2 = NRBUOY
      IF(NRBUOY.GT.24) K2 = 24
      K3 = NRBUOY
      DO 10 I=1,48
      NSONO1 = I
      NSONO2 = 2*I
      NSONO3 = 3*I
      IF(I.LE.K1) WRITE(6,920) NSONO1,PVEC(1,I),NSONO2,PVEC(2,I),NSONO3,
     1PVEC(3,I)
  920 FORMAT(' ',2X,'1',5X,I3,5X,F7.4,20X,'2',5X,I3,5X,F7.4,20X,'3',5X,I
     13,5X,F7.4)
      IF((I.GT.K1).AND.(I.LE.K2)) WRITE(6,930) NSONO1,PVEC(1,I),NSONO2,P
     1VEC(2,I)
  930 FORMAT(' ',2X,'1',5X,I3,5X,F7.4,20X,'2',5X,I3,5X,F7.4)
      IF((I.GT.K2).AND.(I.LE.K3)) WRITE(6,940) NSONO1,PVEC(1,I)
  940 FORMAT(' ',2X,'1',5X,I3,5X,F7.4)
      IF(I.GT.K3) WRITE(6,950)
  950 FORMAT(' ')
      IF(I.EQ.30) WRITE(6,960)
  960 FORMAT('+',27X,'PROGRAM INPUTS')
      IF(I.EQ.32) WRITE(6,970)
  970 FORMAT('+',29X,'PROPLOSS CURVE')
      IF(I.EQ.33) WRITE(6,980) (IDATA(J),J=1,20)
  930 FORMAT('+',29X,'HEADING INFORMATION: ',20A4)
      IF(I.EQ.34) WRITE(6,990) (IDATA(J),J=21,40)
  990 FORMAT('+',50X,20A4)
      IF(I.EQ.35) WRITE(6,1000) FOM
 1000 FORMAT('+',29X,'FIGURE-OF-MERIT:',F6.1,' DB')
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```
      IF(I.EQ.36) WRITE(6,1010) ISUBSP                                  CARD0610
 1010 FORMAT('+',29X,'SUBMARINE SPEED:',I3,' KNOTS')                    CARD0611
      IF(I.EQ.37) WRITE(6,1020) ISUBCS                                  CARD0612
 1020 FORMAT('+',29X,'SUBMARINE COURSE:',I4,' DEGREES TRUE')            CARD0613
      IF(I.EQ.38) WRITE(6,1030) ICUSAC                                  CARD0614
 1030 FORMAT('+',29X,'SUBMARINE COURSE ACCURACY:',I4,' DEGREES EITHER SICARD0615
     1DE OF COURSE')                                                    CARD0616
      IF(I.EQ.39) WRITE(6,1040) X1,X2,X3,X4                             CARD0617
 1040 FORMAT('+',29X,'INITIAL SUBMARINE PROBABILITY AREA: X1=',F7.1,'  XCARD0618
     12=',F7.1,'  X3=',F7.1,'  X4=',F7.1)                               CARD0619
      IF(I.EQ.40) WRITE(6,1050) Y1,Y2,Y3,Y4                             CARD0620
 1050 FORMAT('+',65X,'Y1=',F7.1,'  Y2=',F7.1,'  Y3=',F7.1,'  Y4=',F7.1) CARD0621
      IF(I.EQ.41) WRITE(6,1060) TLATE                                   CARD0622
 1060 FORMAT('+',29X,'TIME LATE:',F5.1,' HOURS')                        CARD0623
      IF(I.EQ.42) WRITE(6,1070) IACSPD                                  CARD0624
 1070 FORMAT('+',29X,'AIRCRAFT ON-STATION SPEED:',I4,' KNOTS')          CARD0625
      IF(I.EQ.43) WRITE(6,1080) IACALT                                  CARD0626
 1080 FORMAT('+',29X,'AIRCRAFT ON-STATION ALTITUDE:',I6,' FEET',/)      CARD0627
   10 CONTINUE                                                          CARD0628
      WRITE(6,1090) LINES,NSONC,PMAX                                    CARD0629
 1090 FORMAT(' ',14X,'OPTIMUM PATTERN:',I2,' ROWS ',I3,' SONOBUOYS - PROCARD0630
     1BABILITY-OF-DETECTION=',F7.4)                                     CARD0631
      NSROW = NSONC/LINES                                               CARD0632
      IF(NSROW.GT.44) GO TO 20                                          CARD0633
      DO 30 I=1,LINES                                                   CARD0634
      J= (I - 1)*NSROW + 1                                              CARD0635
      K = I*NSROW                                                       CARD0636
      IF(NSROW.LE.21) WRITE(6,1100)                                     CARD0637
 1100 FORMAT(' ',//)                                                    CARD0638
      IF(NSROW.GT.21) WRITE(6,1110)                                     CARD0639
 1110 FORMAT(' ')                                                       CARD0640
      IF((I/2)*2.EQ.I) GO TO 40                                         CARD0641
      IF(NSROW.LE.21) WRITE(6,1120) (L,L=J,K)                           CARD0642
 1120 FORMAT(' ',21(3X,I2,'*'))                                         CARD0643
      IF(NSROW.GT.21) WRITE(6,1130) (L,L=J,K)                           CARD0644
 1130 FORMAT(' ',44(1X,I2))                                             CARD0645
      GO TO 30                                                          CARD0646
   40 IF(NSROW.LE.21) WRITE(6,1140) (L,L=J,K)                           CARD0647
 1140 FORMAT(' ',3X,21(3X,I2,'*'))                                      CARD0648
      IF(NSROW.GT.21) WRITE(6,1150) (L,L=J,K)                           CARD0649
 1150 FORMAT(' ',1X,44(1X,I2))                                          CARD0650
   30 CONTINUE                                                          CARD0651
      WRITE(6,1160)                                                     CARD0652
 1160 FORMAT(' ',///' OPTIMUM PATTERN PARAMETERS',/)                    CARD0653
   20 ICREN1 = ISUBCS + 90                                              CARD0654
   50 IOREN1 = ICREN1 - 180                                             CARD0655
      IF(IOREN1.GE.0) GO TO 50                                          CARD0656
      IOREN1 = IOREN1 + 180                                             CARD0657
```

```
      IOREN2 = IOREN1 + 180                                             CARD0658
      WRITE(6,1170) IOREN1,IOREN2                                       CARD0659
 1170 FORMAT('    ORIENTATION:',I4,'/',I3,' DEGREES TRUE')              CARD0660
      WRITE(6,1180) IBOYSP                                              CARD0661
 1180 FORMAT('    SONOBUOY SPACING:',I4,' NAUTICAL MILES')              CARD0662
      WRITE(6,1190) PCX,ISUBCS                                          CARD0663
 1190 FORMAT('    RANGE/BEARING FROM INITIAL SUBMARINE PROBABILITY AREA CCARD0664
     1ENTER TO SONOBUOY PATTERN CENTER:',F7.1,' NAUTICAL MILES/',I3,' DECARD0665
     2GREES TRUE')                                                      CARD0666
      IF(NSONO.GT.16) GO TO 60                                          CARD0667
      WRITE(6,1200)                                                     CARD0668
 1200 FORMAT('    MONITOR ALL PATTERN SONOBUOYS CONTINUOUSLY')          CARD0669
      GO TO 70                                                          CARD0670
   60 WRITE(6,1210) ICYCL,IBMON                                         CARD0671
 1210 FORMAT('    USE',I2,I3,' MINUTE MONITOR CYCLES')                  CARD0672
   70 WRITE(6,1220)                                                     CARD0673
 1220 FORMAT('1')                                                       CARD0674
      RETURN                                                            CARD0675
      END                                                               CARD0676
```

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